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PROTOTYPE PROPELLANT-TESTING SYSTEM

PHASE III - DESIGN AND CONSTRUCTION OF CONTAMINANT-INTRODUCTION SYSTEM

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FOREWORD

This report was prepared by the Chemical Products Division of Aerojet-General Corporation under USAF Contract No. AF 04(611)-8196. This contract was initiated under Program Structure No. 650A, Project No. 3850, Task No. 385003. The work was administered under the direction of the Rocket Propulsion Laboratories, Air Force Systems Command, with Mr. R. A. Biggers (DGPCS) acting as project engineer and Mr. A. V. Jensen (DGPC) as senior engineer, 6593d Test Group (Development).

The report covers work conducted from 13 July 1962 through 31 January 1963 and is the final report on Phase III of the program. It is submitted in partial fulfillment of the contract, is catalogued by Aerojet-General as Report No. 2486, and was prepared in accordance with Air Force Systems Command Manual 5-1 (AFSCM 5-1), as specified by the contract.

ABSTRACT

A prototype contaminant-introduction system was designed and fabricated for the addition of solid, liquid, and gaseous contaminants to storable or cryogenic propellants maintained under diverse conditions. Five separate units - for the addition of solids, liquids, gases, cryogenic liquids, and vaporized liquids - were constructed and tested to demonstrate their capabilities for adding small amounts of impurities for contamination purposes in the range from 10 to 5000 ppm at accuracies of 6 to 20%.

This technical documentary report has been reviewed and is approved.

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I. INTRODUCTION

Each of the many steps involved in the routine handling and transfer of liquid propellants offers an opportunity for the introduction of impurities through the condensation of gases, dissolving of atmospheric contaminants, entrainment of solids, or corrosion of the flow system. In turn, this contamination results in reduced performance or rocket-motor malfunction.

The purpose of this program was to study and to design a prototype system that makes it possible to examine the effects of contaminant on liquid propellants. This report describes in detail a critical portion of the prototype test system, a contaminant-introduction subassembly that was constructed and tested in Phase III of the program. Phases I and II were covered in Ref. 1 and, together with Phase III, are summarized in Section II.

II. OBJECTIVES AND SUMMARY

A study was conducted in Phase I to determine the feasibility of fabricating a prototype propellant-testing system that would facilitate the measurement of solid, liquid, and entrained-gas impurities in a flowing rocket-propellant test system. Consideration was given to a system compatible with liquid oxygen (LO_2), liquid hydrogen (LH_2), liquid fluorine (LF_2), hydrazine (N_2H_4), pentaborane (B_5H_9), tetrafluorohydrazine (N_2F_4), hydrogen peroxide (H_2O_2), and chlorine trifluoride (ClF_3). The system is adaptable for flow filtrations and for particulate and material-compatibility studies. It can be used for analytical tests that involve ultraviolet spectroscopy, infrared spectroscopy, radio-frequency absorption spectroscopy, nuclear-activation analysis, conductivity measurement, photographic observation, and other methods.

A prototype system meeting specific functional requirements was designed in Phase II. The system contains two tanks that hold 200 gal of liquid propellant with a maximum LN_2 loss of 2%/day. The tanks and flow system are capable of handling propellants at temperatures from -420 to +200°F, over a pressure range from vacuum (a few microns of mercury) to 215 psig and at a flow-rate range from 5 to 150 gal/min (gpm). Provisions are made for weighing, venting, filling, evacuating, and pressurizing the vessels, for recirculating the propellant; for monitoring the liquid level and temperature of the propellant; and for disposing of vent gas. Appropriate materials of construction are used to provide compatibility with the representative liquid propellants named above.

The feasibility-study and preliminary-design phases of this program were described in detail in Ref. 1.

The present report covers Phase III, the objective of which was to fabricate a device that could add known amounts of contaminants to propellants. Individual units were designed to add gaseous, liquid, or solid contaminants such that uniform mixing throughout the vessel occurs within 15 min. The contaminants that can be added and the required accuracy of addition are summarized in Table 1. The initially conceived systems are depicted in Figures 1 and 2. An improved assembly was constructed and tested; engineering drawings and operating procedures for the contaminant-introduction system were developed as the work progressed. The final drawings and photographs of

equipment based on them are reproduced as Figures 3 through 19, and the operating procedures are presented in Section VI.

III. DEVELOPMENT OF SYSTEM

First consideration in the design of the prototype contaminant-introduction system was given to a single system that could be used for the addition of all the contaminants. It was subsequently concluded, however, that a single system was impractical and that separate units would be required to permit accurate addition of the variety of contaminants. The advantages and limitations of these approaches are discussed below.

A. SINGLE SYSTEM

Figures 1 and 2 represent systems that were conceived initially for the addition of all types of contaminants to a liquid-propellant test system. The gases or vapors were to be metered at constant temperature and pressure for a suitable period of time. The storable and cryogenic impurities were to be pumped in at a constant rate for a measured period. The solids were to be slurried with a portion of the propellant to which they would be added, and the slurry would then be pumped in a manner similar to the liquids; recycling of the slurry from the pump to the tank would be required to keep the solids uniformly suspended.

Analysis of this system showed that many of the problems involved were beyond the practical limits of routine propellant handling. A constant-temperature bath would have to be designed, for example, so that it could operate from the temperature of LH_2 to temperatures above 212°F. The pumps, meters, and valves would have to be compatible with all the propellants and would be required to operate over the complete temperature range. Moreover, the fluid-density and flow-rate ranges are so great that many different sizes of equipment would be required and the end product would be unwieldy.

B. SEPARATE SYSTEMS

Contaminants are to be added as solids, liquids, and gases, and three addition systems are required, as a minimum. The handling and accurate addition of cryogenic liquids, however, present different problems from those presented by storable liquids. Furthermore, the addition of water vapor presents difficulties not experienced in the introduction of nitrogen or other gaseous impurities. Five contaminant-introduction systems were therefore deemed necessary to accomplish the goals. The various techniques considered for these systems are discussed below.

1. Liquid

Four different types of liquid-addition techniques were considered: (a) direct metering, (b) addition by level from calibrated tanks, (c) multiple discharge from a reservoir, and (d) use of a metering pump.

a. Direct Metering

The direct-metering scheme is complicated by the large variation in the quantities required (a ratio of 2700 to 1). A complex timing device and many meter sizes would be required.

b. Calibrated Tanks

Charging by level from calibrated tanks becomes somewhat complicated, due to the very large quantity variation required. At least four tank sizes, with appropriate level indicators, would be needed. This approach would be direct and accurate but would be somewhat cumbersome.

c. Multiple Discharge

A system was considered for charging liquids from a reservoir located directly above the propellant-metering tank. The reservoir would be closed at the bottom with a ball-type valve fitted with one or more calibrated reservoirs. The valve would be drilled to allow an inert gas to eject the contents of the reservoir into the tank. This system is routinely used for small-scale measurements and provides accurate, reproducible results. It is limited, however, to a total charge consisting of multiples of the calibrated reservoir volume that could not be easily changed. Too many fillings of the reservoir would be required to cover the quantity range specified, and large quantities of inert gas would be introduced into the system.

d. Metering Pumps

The metering-pump approach is a variation of the multiple-discharge method. Many types and makes of metering pumps are available - piston pumps, vane pumps, diaphragm pumps, etc. Experience has shown that the piston-type pump is the most reliable when extremely accurate volumes are required to be delivered over a fairly large range. A pump was selected with one small cylinder and one large cylinder, both adjustable from zero to full stroke. In addition, a stroke counter was provided that stops the pump after any number of strokes up to 400. With this arrangement it is possible to add quickly and accurately the complete range of quantities required (0.6 to 1360 ml) in less than 10 min.

2. Water Vapor

Two methods of adding water vapor (or other vapors) were considered: (a) direct metering, and (b) measuring as a liquid and then vaporizing and adding as a vapor.

a. Direct Metering

Direct metering is difficult, due to the small quantity of water vapor to be added (0.6 to 68 g) and the short periods during which it must be added (less than 15 min). The study showed that accurate metering would be difficult and expensive. A means of superheating the vapor would be required, and an elaborate positive-displacement meter or an integrating flow meter would also be required. Alternately, water vapor could be carried into the propellant by means of an inert gas saturated with water vapor, but

excessive gas would be introduced to the holding vessels and would result in pressure buildup or in loss of propellant during venting.

b. Vaporizing Liquid After Measurement

This method was selected as being simple, accurate, and relatively free of trouble. The rather small range in quantities required (0.6 to 68 g, or a ratio of 113 to 1) can be measured easily in a single, calibrated, gage glass. The vaporizer required is not large or complicated and is simple to operate.

3. Gas

The two basic methods of addition considered here were (a) direct metering, and (b) charging from calibrated cylinders at known temperatures and pressures.

a. Direct Metering

A direct-metering system would be difficult to use because of the very large variation in the quantities to be delivered (a 5000-to-1 variation). Many sizes of meters would be required in order to obtain accuracy in both the low and the high ranges.

b. Charging from Calibrated Cylinders

The method of charging from calibrated cylinders was selected when it was shown that acceptable accuracy could be obtained throughout the whole range of concentrations by using only three cylinder sizes and three pressure-range gages. Each of the cylinders can be attached to the unit by means of matched unions. The operation of this system depends on the measurement of the initial and final pressures and temperatures of the calibrated cylinder.

4. Cryogenic Liquids

The methods considered for the addition of cryogenic liquids were (a) direct metering, and (b) measurement of gas on the basis of the temperatures and pressures of a calibrated cylinder prior to liquefaction and charging.

a. Direct Metering

The difficulties associated with the temperature, pressure, and flow control required in the accurate metering of cryogenic liquids are far beyond the capabilities of a practical system for routine work. It is difficult to use metering pumps for cryogenic liquids because of the refrigeration required; flashing of the liquid in the piston or in the check valves would make the accuracy of this method questionable. Similarly, the measurement of cryogenic liquids from calibrated tanks imposes much more difficult problems than those associated with normal liquids, due to the necessity for accurate liquid-level indication at low temperatures.

b. Condensation and Charging of Liquefied Gas

This method consists of measuring the cryogenic material as a gas and then condensing it to a liquid before adding it to the propellant system. Because all the cryogenic liquid that is condensed would be added, it is not necessary to measure its volume or weight. The cryogenic liquid is charged to the propellant system either by its own vapor pressure or by the use of an inert gas (e.g., helium). Experience has shown that it is necessary to provide two systems (one large and one small) in order to achieve the specified accuracy over the wide ranges required. The systems are manifolded together for simplicity of operation.

5. Solids

Solids may be added as slurries or may be measured directly into the propellant vessel as solids.

a. Slurries

The addition of solids by slurrying with propellant was considered initially, and the single systems shown in Figures 1 and 2 were conceived for the preparation of slurries. The amount of slurry introduced to the propellant vessel was to be determined by a metering device or by the measurement of liquid level. Prohibitive problems exist, however, in the areas of maintaining a uniform suspension, of obtaining accurate liquid-level indication, and of compensating for heat exchange and material loss in the cryogenic system.

b. Dry Solids

Many types of solids feeders are commercially available - belt conveyors, screw conveyors, vibratory feeders, etc. Most of them, however, have minimum capacities that are too great to permit accurate measurement of the small quantity of solids to be added (0.2 to 10 g). The addition of solids to a closed system imposes further complications. The solids-addition equipment must be designed so that it can discharge directly into the propellant-test system, or the unit would have to discharge into a lock hopper that, in turn, could be discharged into the propellant-test system. Because of the very corrosive propellants to which some of the solids must be added, the latter approach was adapted as the most practical. This approach permits the use of relatively simple, commercially available, solids-handling equipment.

A small vibratory feeder that could be adapted to deliver the required quantities of solids was examined. Tests were made that showed the quantities delivered at a given setting were reproducible to within ± 2 to $\pm 5\%$ over the desired range. It was decided not to use this equipment, however, because the delivery of solids depends upon vibration, and segregation of the various particle sizes became a problem.

A variation of the continuous solids feeder is the multiple-displacement feeder, which discharges measured quantities of solids from a fixed-volume or variable-volume chamber. A simple device of this type, a microsetting powder measure manufactured by the Santa Anita Engineering

Company,* was tested and found to deliver the specified amounts of solids (silica) with a ±2% accuracy throughout the quantity range required. Visual observation showed no particle-size segregation such as that detected during the use of the vibratory feeder.

IV. DESCRIPTION OF PROTOTYPE SYSTEM

The system is designed to add contaminants to a 200-gal, multiwall, cryogenic tank. Because the tank requires a manhole for access for cleaning, it was logical that this opening should also be used for additions from the contaminant-addition system; this approach would minimize the number of openings and consequently the leakage of heat into the tank. The propellant system requires a pump or means of recirculation, a vacuum system, and inert-gas purges. These utilities have been assumed to be available at the site where the contaminant-addition system is used.

A. FLANGE

All five individual units connect to a single flange (see Figures 3 and 4). The flange is designed to withstand pressures from a vacuum (a few microns of mercury) to 215 psig at temperatures from -420 to +200°F in the tank. A special serrated seal with a soft-copper gasket is required to withstand the extremes of temperature and pressure, as well as corrosion. A 4-in.-deep vacuum jacket is provided on top of the flange to minimize the heat leakage, and a baffle plate is attached to the tubes 15.5 in. below the bottom of the flange to provide a dead space in the vapor for additional heat-loss protection. The three separate entry tubes extend 16 in. below the flange so that they will discharge into the main part of the cryogenic storage tank rather than into the manhole neck. The flange and parts exposed to the propellants are all of Type 347 or other Series 300 stainless steels for maximum compatibility with the propellants.

Lifting lugs (see Figure 4) welded to the top of the flange provide for ease of mounting and disassembly. They also serve as mounting brackets for the cryogenic-addition and solids-addition equipment. Stainless-steel unions are provided on the tops of the two outer tubes for ease of connection with the gas and the solid systems. Plugged half-unions are provided to seal these unions when the respective systems are not in use. The center tube (spary-injection tube) is provided with a 1/4-in. standard flared (AN) fitting that is used to connect the cryogenic-addition system, the water-vapor-addition system, or the liquid-addition system. This fitting is also capped when not in use.

The spray nozzle (see Figure 5) is provided with an electric heater to control the temperature of the inner tube so that vapors will not condense, or liquids will not freeze, during injection. A vacuum jacket is

*3270 Foothill Blvd., Pasadena, California.

provided around the heater to minimize heat flow between the heater and the tank. The heater is explosion-proof and is provided with an explosion-proof terminal box; however, the lead cord used temporarily for testing should be replaced by permanent explosion-proof wiring. The thermocouples in the spray tube are of Chromel-Alumel and are terminated in standard-junction blocks.

A 3/16-in. copper-tubing coil is provided around the upper end of the spray tube and valve. It should be connected to a source of LN_2 during the cryogenic-injection tests and to a source of steam at 100 psi during water-vapor injection.

B. LIQUID-ADDITION UNIT

The flow diagram for this unit is presented in Figure 6, and the assembled equipment is shown photographically in Figure 7. The unit consists of a metering pump with a feed tank and auxiliary piping connected to the spray nozzle of the injection flange. The pump is a Proportioneers Duplex Adjust-O-Feeder Model 1106* with one 1/4-in. and one 5/8-in. cylinder. An H-2 series Microflex stroke counter is provided to shut the pump down after any number of strokes up to 400. With this arrangement, it is possible to meter liquids into a propellant system with good accuracy over the entire range from 0.6 to 1360 ml at pressures up to 200 psig. Valves are provided for calibration of the pump-discharge rate and for flushing the liquid from the lines with inert gas or recycled propellant.

The pump, feed tank, and piping are constructed of stainless steel for corrosion resistance and to prevent extraneous contamination. The pump packing is of Teflon and does not need lubrication for the short operating periods required (less than 15 min). The check valves and relief valves have Teflon seats and are therefore compatible with all liquids except ClF_3 and related compounds. Teflon tape is used on the threaded pipe connections because of its compatibility with nearly all liquids; it has been found to prevent the galling of stainless-steel threads and to make good leak-tight connections.

The pump motor and the microswitch mounted on the pump are both explosion-proof; it is therefore possible to mount the pump near the top of the propellant tank. The Microflex counter box is not explosion-proof and should therefore be mounted in a nonexplosive area.

C. WATER-VAPOR-ADDITION UNIT

This unit, illustrated in Figures 8 and 9, consists of a specially calibrated gage glass (Figure 10) and a U-shaped, electrically heated vaporizer (Figure 11), which is connected directly to the spray nozzle of the flange. The unit is designed to measure and vaporize the 0.6 to 80 g of water (or similar liquid) and to add it to a closed propellant system in less than 15 min.

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*C. P. Crowley Company, 5430 Jilson St., Los Angelss 22, California.

The vaporizer is constructed of a 10-ft length of Type 304 stainless-steel tubing bent in a "U" shape. The tube is insulated with glass tape and wrapped with Nichrome wire to provide approximately 1000 watts of heat. Chromel-Alumel thermocouples silver-soldered to the tube provide points for the monitoring of temperature. Additional insulation is used over the heater, and the entire unit is enclosed in a 2-in.-OD tube to make it explosion-proof. A variable transformer (0 to 110 v) of 1000-watt capacity is required as auxiliary equipment for this unit; a temperature indicator (or recorder) is also required for use at the Chromel-Alumel thermocouples located in the vaporizer and in the spray tube.

D. GAS-ADDITION UNIT

This unit, illustrated in Figures 12 and 13, consists of a series of calibrated gas cylinders connected directly to the 1/2-in. discharge tube in the flange. Three cylinders having capacities of approximately 0.44, 4.08, and 44.0 liters are provided. These volumes include the volume of the associated piping, as determined by the calibration procedure. The three cylinders can be connected interchangeably in the system by means of matched 1/4-in. unions. The small and medium-size gas cylinders are of stainless steel for maximum corrosion resistance. Two large cylinders of identical size are supplied for the addition of maximum quantities of gases; they are constructed of mild steel and their use is therefore limited to clean, dry, noncorrosive gases such as nitrogen, methane, and carbon dioxide. All the gas cylinders are designed to operate at pressures up to 1800 psig.

Three precision pressure gages are supplied (0 to 60, 0 to 600, and 0 to 2000 psi) for accurate pressure measurement at all levels of gas addition. Another pressure gage (0 to 300 psi) is provided to indicate the pressure in the manifold during gas addition.

Copper-constantan thermocouples installed in each of the gas cylinders permit accurate measurement of the temperature before and after each gas addition. The piping is assembled in three units or manifolds (A, B, and C of Figure 12) that can be quickly and easily assembled at the pipe unions or flared-tubing connections.

A check valve installed in Manifold B is designed to prevent possible backflow of propellant into the gas cylinders. All piping and valves are of stainless-steel construction. All valves have Teflon packing and metal-to-metal seats. Valves that may be in contact with cryogenic propellants have extended bonnets so that they will not freeze.

E. CRYOGENIC-LIQUID-ADDITION UNIT

The cryogenic-liquid-addition system is shown schematically in Figure 14 and photographically in Figure 15. It is the most complex of the five units. The gas-addition equipment is used to measure the contaminants as gases at ambient conditions. Then, depending upon the quantity to be added, the gases are fed into one of two condensing units. The larger quantities (400 to 4000 g of CH_4 or 600 to 6800 g of N_2) are condensed batchwise in the large condenser (see Figure 16). The smaller quantities (0.8 to 400 g of CH_4 or 0.8 to 600 g of N_2) are condensed in the small unit (see Figure 17). After condensation has been completed in the large condenser, the cryogenic

liquid is allowed to flow through the spray tube into the propellant system under its own vapor pressure. The small unit operates in a continuous manner - i.e., the liquid is sprayed into the propellant system as fast as it condenses. Helium or another low-boiling inert gas is used to purge the remaining liquid from the condensing coils at the end of a run.

Liquid nitrogen or another refrigerant is used in the large and small condensing units. The piping outlet from the refrigerant-storage tank is common to both units, thus permitting a single control system for either unit. A series of springs (50, 100, 159, 200, and 250 psi) are supplied for the relief valve so that the pressure (or temperature) on the refrigerant system can be maintained at a value that will permit the condensed gas to maintain sufficient vapor pressure to flow into the propellant system within a 15-min period. Valves are provided so that the large condensing unit can be isolated when the small unit is in use, and vice versa. A 3/16-in. coil of copper tubing is provided around lines from the large and small condenser that connect to the injection valve. Liquid nitrogen or another refrigerant is used in the coil to chill the lines and thus to prevent flashing of the condensed gas as it is charged into the propellant system.

F. SOLIDS-ADDITION UNIT

The solid-contaminant-addition unit is shown schematically in Figure 18 and photographically in Figure 19. It is the simplest of the five units. The equipment consists of a precision powder-measuring instrument and a storage chamber mounted on top of the flange. The powder measurer is hand-operated and can be calibrated to deliver from 0.2 to 10 g (of silica) per stroke. Because it does not come in contact with any of the propellants, either steel or cast iron is a satisfactory material of construction.

The storage chamber is simply a short length of 3/4-in. stainless-steel pipe contained between two 3/4-in. ball valves. Connections to the storage chamber are provided for the introduction of inert gas or recycled propellants to wash the powder from the chamber into the propellant system. The ball valves are of stainless steel, have Teflon seals and extended bonnets for cryogenic service, and are designed for either pressure or high-vacuum service.

G. COMPONENTS AND ACCESSORIES

Commercially available parts are incorporated wherever possible in the prototype contaminant-addition system, and many of the valves may be used interchangeably. If the system is to be employed frequently, replacements should be obtained for the valves that are most frequently used. The small needle valves and pump-packing replacements are obtainable with little delay, but the delivery schedule for valves with extended stems is approximately 60 days.

The flange, liquid vaporizer, condensers, and other components shown in Figures 3, 4, 5, 10, 11, 16, and 17 were specially fabricated for this program, and replacements must be constructed as required. Several accessory items should be available for the operation of the prototype contaminant-introduction system.

Tables 2, 3, and 4 list the various valves, gages, and special items provided as part of the prototype system and give the pertinent specifications for the individual components. Table 5 itemizes the accessories required. These instruments and accessories, miscellaneous tubing and connections, and the items described in the drawings constitute the contaminant-introduction system.

V. TESTING AND CALIBRATION

The five contaminant-addition units were tested and calibrated to demonstrate their ability to meet specifications set forth in the contract.

A. LIQUID-ADDITION UNIT

This unit was assembled as shown in Figure 7 and was tested with water. All piping was checked for leaks at a pressure of 300 psig. Both pump cylinders were checked for adjustment and were found to be continuously adjustable from 0 to 100% of full stroke. The pressure-relief valve was found to release at 200 psig and to reseat with no leakage. The pump check valves were found to hold pressure with no leakage. The pump was allowed to operate against a 200-psig discharge for periods of 15 min or longer, and there was no heat buildup or other damage. The H-2 series Microflex counter was operated at settings of 5, 15, 40, and 140, and was found to shut the pump down reproducibly after the indicated number of strokes. The capacity of the pump was found to exceed the nominal 1.25 cc/stroke for the 1/4-in. plunger and the 7.55 cc/stroke for the 5/8-in. plunger.

A series of tests (see Table 6) were made to demonstrate that the unit would deliver the liquid into a propellant system at the required rate and accuracy. In these calibrations the pump was operated at various pump-stroke and Microflex-counter settings for both the large and the small cylinder. With the calibrating valve (V-4 of Figures 6 and 7) open, the quantity of water delivered was collected and measured in a graduated cylinder. Next, the calibrating valve was closed and water was delivered through the spray nozzle. After the pump had shut down, the pump-shutoff valve was closed and 50 ml of trichloroethylene was flushed through the recycle valve to wash the residual water from the lines and spray tube; this procedure simulated purging by recycling propellant. The amount of water collected from the spray nozzle was then compared with the amount collected in the calibration run.

An error of 17% in Run 2 resulted from the fact that it was extremely difficult to wash all the water from the lines with the small quantity of trichloroethylene used. In purging with recycled propellant, the higher velocity would assure that the liquid in the lines would be washed out more completely.

B. WATER-VAPOR-ADDITION UNIT

The gage glass used in this unit was calibrated by delivering water from a 50-ml standard laboratory buret. The results were as follows:

Buret Reading ml	Gage Glass Reading mm	Gage Glass Calibration mm/5 ml	Buret Reading ml	Gage Glass Reading mm	Gage Glass Calibration mm/5 ml
10	33	--	60	401	37
15	71	37	65	438	37
20	107	36	70	475	37
25	145	38	75	512	37
30	181	36	80	549.5	37.5
35	217	36	85	586.5	37
40	254	37	90	622	36
45	291	37	--	-	--
50	327	36	--	-	--

The foregoing data show that on the average a 36.8-mm distance on the gage glass corresponds to 5 ml of liquid delivered (7.36 mm/ml, or 1 mm/0.136 ml). The probable deviation is $\pm$1 mm or $\pm$0.14 ml.

Following calibration, the system was assembled as shown in Figures 8 and 9. A water-cooled condenser and a receiving flask were attached to the outlet of the spray nozzle. A steam line was connected to the coil of copper tubing around the injection valve to prevent condensation. The gage glass was filled with water, the heater was adjusted to give the proper temperature, and water was vaporized and collected. The results of these tests are summarized in Table 7.

The data indicate that in the addition of large amounts of contaminants excellent addition accuracies were achieved; in the addition of small quantities care must be taken to achieve the required accuracy. The 1/8-in. line extending from the shutoff valve at the bottom of the gage glass must be filled completely before a run is started. The injection-valve temperature must be above 212°F, so that steam does not condense in the valve. After closing the shutoff valve, it is necessary to wait 3 to 4 min before shutting the injection valve and measuring the water recovered; the additional time is required to vaporize the water in the first portion of the vaporizer.

A check of the capacity of the vaporizer was made in which the rate of water addition was set at approximately twice the required rate to determine if water would come through the vaporizer instead of steam. A total of 74 ml of water was charged through the vaporizer in 6.6 min. Although the indicated temperature in the middle of the vaporizer fell below 212°F, the outlet temperature fell to only 272°F, indicating that steam was still coming out of the vaporizer. In this test the vaporizer Variac was set at 70 v. With a higher electrical input the internal temperature would not have fallen below the boiling point. It is therefore clear that the vaporizer is capable of operating at greater than the required rate. The unit can easily vaporize the maximum quantity of water for short periods of time and at the required flow rates.

C. GAS-ADDITION UNIT

The gaseous-contaminant-addition unit includes three sizes of gas cylinders (see Figure 13). In order to obtain accurate measurements of the quantity of gas added, it is necessary to know the volume of the system used and to know the absolute pressures, temperatures, and gas densities at the beginning and end of the tests. The volume of the gas system in each case includes the volume of the gas cylinder, the pressure gage, and the piping up to the shutoff valves (V-14 and V-23 of Figure 12 or 13). The volumes of each of the three systems were measured (1) by filling the entire system with water, and (2) by measuring the volume of dry nitrogen contained in the system with a wet test meter (WTM). The results agreed within ±1 to ±2% in all cases. The values obtained from the WTM are believed to be more accurate because of the difficulty of completely filling the manifold and pressure gage with water. The results of the calibration are given below.

System		Calibrated Volume
Cylinder Size	Range of Pressure Gage in Manifold, psi	liters
Small	0 to 60	0.445
Small	0 to 600	0.435
Small	0 to 2000	0.435
Medium	0 to 60	4.09
Medium	0 to 600	4.08
Medium	0 to 2000	4.08
Large	0 to 60	44.0
Large	0 to 600	44.0
Large	0 to 2000	44.0

The two large gas cylinders supplied with the unit have the same volume to permit their use interchangeably. If both cylinders are to be used simultaneously by connecting the second cylinder into the manifold through the bleed valve (V-13), the total volume of the system would be 87.9 liters. The larger volumes may be required for the addition of very large quantities of gases such as CO_2, which tends to liquefy at moderately high pressures.

If the pressure on the inlet-nozzle gage (G-3) is different before and after the gas has been added to the propellant system, a correction must be made for the change in quantity of gas in the manifold between the shutoff valves (V-23 and V-14) and the injection valve (V-22) (see Figure 12 or 13). This volume was measured and found to be 0.266 liter when a 3.0-ft length of 1/2-in. (0.040-in.-wall) tubing was used to connect the piping manifolds designated as A and B. When other lengths of tubing are used to connect the manifolds, a correction should be made to allow for the difference in the volume of the tube.

A series of tests were made on the gaseous-contaminant-addition system to demonstrate its accuracy and capability. The system was connected as shown in Figure 13; a WTM was connected to the bottom of the 1/2-in. pipe through which the gas enters the propellant tank. The results of these tests

are given in Table 8. Tests 1 and 2 indicated that metering accuracies of the order of ±3% can be expected when small and medium quantities of gas are added. Test 3 indicated that the expected accuracy will decrease somewhat if the wrong pressure gage or the wrong size of gas cylinder is used and a relatively small pressure drop is obtained during the run. Improved accuracies or lesser deviations should be expected for the runs in which larger volumes are added. Test 4 was made to demonstrate that the larger quantities of gas can be added successfully in the required length of time.

D. CRYOGENIC-LIQUID-ADDITION UNIT

1. Large Condensation Unit

This unit was set up as shown in Figures 14 and 15; the valves that isolate the small unit were closed. Two runs were made with the large unit to demonstrate satisfactory operation at the upper range of quantities desired. Nitrogen gas was condensed and discharged in each of these tests; LN_2 at 50 to 100 psig was used as the refrigerant. The test data are given in Table 9.

The first test was made to demonstrate that large quantities of gas can be condensed and then added as a liquid in the required length of time. A period of 35 min was required to condense the nitrogen; during this time the pressure in the liquefied-gas tank was held at about 175 psig by adjusting the shutoff valve (V-23). The pressure on the refrigerant tank was allowed to build up to about 100 psig during the run. The relief valve (V-20) operated satisfactorily to maintain this pressure. Near the end of the condensing cycle, the pressure on the refrigerant tank was allowed to drop to 65 psi; after the nitrogen gas to the condenser was shut off, the pressure on the condenser tank fell quickly to that in the refrigerant tank (about 60 psi). Nine minutes was required to discharge the condensed nitrogen through the spray tube. Because the maximum time allowed for discharge is 15 min, this test demonstrated that the maximum quantity of LN_2 can be discharged in the required time.

In the second test, smaller quantities were introduced through the large cryogenic-addition unit. Approximately 3.5 min was required to condense the required amount of nitrogen. Again, the pressure on the refrigerant tank was allowed to build up so that the vapor pressure of the condensed nitrogen would be high enough to discharge it into the test system. Only 1 min and 25 sec was required to discharge the condensed nitrogen in this test. No attempt was made to measure the actual quantity of LN_2 discharged, because the tests of the gas-addition system showed that the gas can be added with an accuracy of ±3 to ±5%. A correction must be made for the quantity of gas left in the liquefied-gas tank and in the manifold between the shutoff valve (V-23) and the liquefied-gas tank; the method of correction is given in paragraph 4.7.4 of Section VI. The volume of the liquefied-gas tank is 9.60 liters, and the manifold outside the tank has an additional volume of 0.27 liter, assuming that a 3.0-ft length of 1/2-in., 0.049-in.-wall tubing is used to connect the A and B piping manifolds (see Figure 14). These volumes, along with the temperatures and pressures, are used to make the necessary correction.

2. Small Condensation Unit

The small condenser for liquefied gases was assembled as shown in Figure 15. This condenser is to be used for charging quantities up to approximately 1 lb to the propellant vessel. For these tests, as for the large unit, LN_2 was used as the refrigerant and gaseous nitrogen was condensed and discharged through the spray nozzle. The test results are given in Table 9.

In this condenser the contaminant gas is introduced, condensed, and charged into the propellant vessel continuously. For precise work the condenser tubing is purged with helium after the contaminant gas is closed off. Seven runs were made with the 4.080-liter gas cylinder - two at approximately 0.5 lb charged, two at 0.05 lb, and three in the 0.01-lb range. All were made using the precision gage with a range from 0 to 2000 psi. Moderately high pressure was used in the gas cylinders to permit a pressure of 50 to 80 psig to be maintained in the condensing coil; this resulted in condensation at a slightly higher temperature than that of the refrigerant, which was vented at atmospheric pressure.

The two 0.5-lb runs were throttled to require a charging time of about 15 min. Smaller quantities cannot be accurately throttled by means of this gage and cylinder. Runs in the minimum range, less than about 25 g, can most accurately be made from the small cylinder, using the pressure gage with the lowest possible range. As the charging time decreases it becomes more difficult to end charging at a precise, predetermined pressure, although there is no difficulty in reading the gage with suitable accuracy.

The two runs at approximately 0.05 lb are at about the limiting rate with the medium-size cylinder. These runs were controlled to a pressure drop of about 1 psi/sec on the cylinder-pressure gage. The total charge required is about 2 min.

Runs 5, 6, and 7 were made for information purposes only. It was found that there is insufficient time for condenser-pressure corrections or throttling-rate corrections. The small cylinder should be used for charges of this magnitude, and it would be preferable to use the gage reading from 0 to 60 psi.

To ensure condensation, the pressure in the condenser coil must be maintained at least 20 psi above the pressure in the jacket; these pressures are as measured by G-3 and G-4, respectively. This operation can only be performed by throttling with V-8. The proper charging procedure would be to crack V-8 initially and then to adjust the rate of pressure drop with V-23. Valve V-8 is then readjusted to maintain a pressure of 50 to 75 psi in the coil, as read from G-3.

E. SOLIDS-ADDITION UNIT

The accuracy and reproducibility of the powder-measuring unit was determined with commercial sandblast sand (silica) that had been screened to remove particles larger than 250 microns. (A screen analysis showed that the remaining sand had a nearly logarithmic size distribution.) The results,

presented below, show the precision with which sand may be measured; incremental addition of solids having higher or lower densities would deliver higher or lower weights of contaminants.

Setting	Weight of Sand Delivered, g							Reproducibility
	Run 1	2	3	4	5	6	7	±%
1	0.218	0.220	0.220	0.222	0.223	0.225	0.226	2.2
2	0.681	0.692	0.690	0.687	0.686	0.686	0.683	1.7
3	2.28	2.28	2.30	2.32	2.32	2.33	2.35	1.7
4	3.41	3.43	3.43	3.42	3.44	3.42	3.42	0.6
5	9.27	9.09	9.01	9.07	9.13	9.16	9.20	1.6

Following this calibration, the solid-contaminant addition system was set up as shown in Figures 18 and 19. A beaker was placed under the outlet pipe to catch the solids as they were washed through with distilled water from the recycle valve (V-7). The solids were then filtered and dried, and the weights were compared with the weights delivered during calibration. The data are given in Table 10.

The deviation found for Tests 3 and 4 is well within the ±6% allowable error, and serves to demonstrate that the unit will perform satisfactorily at this higher level of addition. Runs 1 and 2 showed larger losses, but the results are still within the allowable limit. A small amount of solids conceivably remained in the lines because of the relatively low velocity of the distilled water used in washing the solids from the lines and tubing. In operation, propellant recycled at a relatively high velocity would provide improved recovery.

VI. OPERATING PROCEDURES

Operating procedures are presented below in a format designed to facilitate future use as an instruction manual, if desired.

1.0 Scope

This equipment has been designed to permit the addition of solid, liquid, or gaseous material to a vessel containing liquid rocket propellant. Contaminants are charged through an 18-in.-dia flange equipped with three introduction tubes. Liquid addition utilizes a metering pump; water-vapor addition is accomplished by feeding a measured volume of water through a vaporizer. Gaseous contaminants are introduced from calibrated gas cylinders and are measured by means of pressure and temperature differential; liquefied-gas contaminants are measured volumetrically as gas, are condensed, and are then introduced to the vessel. Solid contaminants are metered batchwise by the use of a precision powder measure.

2.0 Liquid-Addition Unit

2.1 Description

Impurities that are liquid at normal temperatures and pressure are charged into a vessel containing liquid propellants in a continuous-pulse flow. The two-plunger metering pump transfers the liquid from a 10-liter supply tank to the propellant vessel at any rate from 0 to 270 ml/min. Volumetric measurement is indicated by the number of strokes of the pump during the charging period. The pump is equipped with a stroke counter that will automatically shut off the pump after a preset number of full strokes. The rate of flow through each cylinder may be altered by adjusting the stroke length from zero to the maximum; either cylinder or both cylinders may be in operation.

2.2 Equipment

The metering device is a Proportioneers Duplex Adjust-O-Feeder Model 1106 plunger pump. The small cylinder is equipped with a 1/4-in.-dia plunger and the larger with a 5/8-in.-dia plunger. The pump operates at a maximum of 34 strokes/min, producing flow rates of 42 ml/min in the smaller cylinder and 270 ml/min in the larger cylinder. Valves are included to permit diversion of the stream for calibration and to provide purging of the line downstream from the pump with inert gas or recycled liquid.

The piping consists of an in-line system from the supply tank to the pump and from the pump to the spray nozzle into the propellant vessel, as indicated in Figures 6 and 7. A return line with a relief valve is located between the pump and supply tank to prevent damage to the pump if downstream valves are closed. The supply tank is mounted on the brackets of the pump frame. Operation consists of filling the supply tank with the fluid contaminant, starting the pump, and opening the diversion line for calibration. After the stroke settings have been adjusted and calibrations have been made, the diversion line is closed and the downstream line is purged with propellant or inert gas. The control valve is opened and the pump is operated for the desired number of strokes. The control valve is then closed, and the contaminant is purged into the vessel by recycling propellant from the tank.

2.3 Preparation

The supply tank, pump, and piping must be clean to the degree required for the particular contaminant and propellant to be used. Lubricants should not be used in this unit in any location where they would contact the contaminant stream. The pump plungers are equipped with Teflon seals and do not require lubrication.

The pump calibration should be checked each time the stroke length is adjusted; the stroke-length indicator scale cannot be reset with sufficient accuracy to permit the use of a previous calibration. The pump must be stopped for adjustment of the stroke length. The locknut of the crank pin is loosened and the adjusting screw is turned until the pointer on the indicator scale is at the desired reading.

2.4 Setup Procedure (See Figures 6 and 7)

a. Locate the pump assembly approximately 3 ft from the charging flange.

b. Mount the supply tank on the bracket of the pump frame.

c. Connect the piping between the supply tank and the pump.

d. Connect the piping assembly between the pump and the center union on the charging-flange cover, adjusting the pump location as necessary.

e. Connect the propellant-recycle line to V-26.

f. Connect the pressurizing line to V-1.

g. Connect the fill line to V-2.

h. Connect the vacuum lines, heating cord, and thermocouples as required.

i. Cap the contaminant-addition lines that are not being used.

2.5 Operation

a. Fill the supply tank with liquid contaminant through V-2.

b. Close V-5 and V-26.

c. Open V-1, V-3, and V-4.

d. Start the pump and allow liquid to fill the system, discharging through V-4.

e. Fill the discharge lines with liquid by closing V-4 and allowing both cylinders to recycle to the feed tank through the pressure-relief valve (V-21).

f. Stop the pump and set the stroke counter for the desired number of strokes.

g. Start the pump, collecting liquid from V-4 in the graduated cylinder.

h. Adjust the stroke length if required, and repeat the foregoing step (g).

i. Set the stroke counter for the desired number of strokes.

j. Close V-4.

k. Open V-5 and V-8.

l. Start the pump for the charging cycle.

m. When the pump stops, close V-5.

n. Open V-26 slowly, and purge the line for 30 sec.

o. Close V-26 and V-8.

p. Repeat the foregoing steps as necessary for additional contaminant.

2.6 Shutdown Procedure

a. Disconnect the piping at the charging-flange union.

b. Empty the feed tank.

c. Pump a suitable solvent through the system, discharging at V-4 and V-5.

d. Disassemble the unit in reverse order, using appropriate safety measures.

e. Clean all the assemblies using the appropriate cleaning schedules (Ref. 2).

f. Dry the components and store them in dust-tight enclosures.

3.0 Water-Vapor-Addition Unit

3.1 Description

This unit is used to charge water vapor to an enclosed propellant vessel at a known rate and a known temperature. The charging is continuous; liquid water is drawn from a calibrated gage glass and is then vaporized in a 1000-watt, electrically heated, U-shaped vaporizer. The addition rate is controlled by a manually adjusted valve in the liquid-water line. The vapor enters the propellant vessel through a spray nozzle that is a part of the charging-flange assembly. The arrangement of the unit is shown in Figures 8 and 9.

3.2 Equipment

The water-metering device is a 100-ml-capacity, 3/4-in.-OD, gage glass with a liquid-level slide bar. A 1/8-in. tube and a Hoke valve permit the control of water flow to the vaporizer. The gage is calibrated in millimeters; the flow is adjusted at V-11 and a stopwatch is used to determine the rate of flow. The vaporizer is equipped with leads from the heating element for connection to a 1-kw variable transformer (not supplied). Chromel-Alumel thermocouples are located on the wall of the inner pipe at two points for connection to a potentiometer or other temperature indicator or recorder (not supplied). Two similar thermocouples are positioned on the inner pipe of the spray nozzle. This tube is heated by a 100-watt electric coil controlled by a 500-watt variable transformer (not supplied). Copper tubing is coiled around V-8 and the adjoining pipe; the tubing should be connected to 100-psi steam to prevent condensation in the valve and piping.

3.3 Preparation

The gage glass, piping, and valves must be cleaned of organic materials or solid materials that might obstruct the spray nozzle. The use of deionized or distilled water as the contaminant to be added is recommended to avoid scaling on the inner surfaces of the vaporizer and spray nozzle.

The rate of addition should not exceed the capacity of the heater to vaporize the liquid; the rate can be adjusted rapidly after the addition of liquid has started. The temperatures at all thermocouples must remain above 212°F. The midpoint of the vaporizer should be at approximately 500°F to ensure rapid vaporization. Damage may occur if the temperature exceeds 650°F in either the vaporizer or the spray-nozzle tube.

3.4 Setup Procedure (See Figures 8 and 9)

a. Connect the vaporizer-discharge piping to the spray nozzle on the charging-flange cover.

b. Connect the vaporizer-inlet piping to the gage-glass union.

c. Connect the thermocouple leads to the indicating instrument.

d. Connect the heater leads to the variable transformers.

e. Connect the pressurization gas to the gage-glass inlet (V-10).

f. Connect 100-psi steam to the copper coil around V-8.

g. Set the variable transformers at about 45 v on the vaporizer and 60 v on the spray-nozzle heater for warmup. Do not set the transformers on full voltage unless liquid is flowing; damage may otherwise occur.

3.5 Operation

a. Close V-11 and V-8.

b. Fill the gage glass with deionized water through V-9, making sure that there are no gas bubbles in V-11 and the 1/8-in. line that extends into the vaporizer. Note the level.

c. Close V-9.

d. Open V-10, and pressurize to 20 psi above the pressure of the propellant vessel.

e. Slide the liquid-level bar down to the level required for the total volume of water to be added.

f. Adjust the heaters to provide a minimum of 500°F in the vaporizer and 250°F in the spray nozzle.

g. Immediately before charging, adjust the vaporizer heater to a 50% greater input than required under the foregoing static conditions.

h. Open V-8.

i. Open V-11 slowly, checking the addition rate to obtain the desired flow. Do not add water at a rate exceeding 15 ml/min (100 mm/min), the approximate capacity of the vaporizer.

j. Readjust V-11 and the heaters to maintain the desired conditions during the run.

k. When the liquid level reaches the slide bar, close V-11 and reset the Variac for a vaporizer temperature of 500°F.

l. Wait 4 min, and close V-8 and V-10.

3.6 Shutdown Procedure

a. Disconnect the thermocouple and heater leads.

b. Release the system pressure slowly through V-9.

c. Disconnect the vaporizer at the spray nozzle.

d. Open V-11 and V-10, and purge the remaining water through the unit.

e. Disassemble the unit in reverse order.

f. Clean all the assemblies, using the appropriate cleaning schedule (Ref. 2).

g. Dry all components and store them in dust-tight enclosures.

4.0 Gas-Addition Unit

4.1 Description

Quantitative addition of gaseous contaminants to a liquid propellant is accomplished by pressurized transfer. Three calibrated cylinders are provided; by measurement of pressure and temperature differentials, they permit accurate and reproducible charging over a wide volume range. The maximum rate of flow is dependent on the initial cylinder pressure; the rate of addition is controlled by manually operated valves. This unit is illustrated in Figures 12 and 13.

4.2 Equipment

Gas cylinders with capacities of approximately 44, 4, and 0.4 liters are included; each is equipped with a thermocouple to indicate the gas temperature.

Three precision pressure gages are included to cover the ranges from 0 to 60 psi, 0 to 600 psi, and 0 to 2000 psi. Another pressure gage is installed in the piping assembly designated as B in Figure 12 to measure the pressure in the line that introduces gas into the propellant vessel. A connection is provided to allow the recycling of propellant from the storage vessel for use in purging the introduction line if desired. To prevent a possible flow of propellant-contaminated gas into the calibrated cylinders, a Circle Seal check valve is included in the piping system. Gas flows into the propellant vessel through an open tube in the charging flange.

4.3 Preparation

The gas cylinders, valves, and piping must be clean to a degree commensurate with the gas and propellant in use. No lubricants are required in this unit.

If the piping is not modified, no additional calibration is required. The volume of gas delivered may be determined from the instrument readings, as outlined in paragraph 4.7. Inasmuch as pressure measurements are the basis of accuracy in this unit, all pipe and tube fittings must be leak-tight over the pressure range in use.

4.4 Setup Procedure (See Figures 12 and 13)

a. Connect Piping Assembly B to the 1/2-in. union on the charging-flange cover.

b. Connect Piping Assembly A to the calibrated gas cylinder.

c. Connect Piping Assembly C to Assembly B.

d. Connect Assembly A to Assembly B with the 1/2-in. tubing supplied.

e. Connect the contaminant-gas source to V-13.

f. Connect the vacuum line to V-17.

4.5 Operation

a. Close all the valves except V-12, V-14, and V-16.

b. Evacuate the calibrated cylinder and piping assemblies.

c. Close V-17 and V-14.

d. Open V-13 and fill the calibrated cylinder to the required pressure (see paragraph 4.7 for calculations).

e. Close V-13.

f. Pressurize the piping assemblies with the contaminant gas by cracking V-14; close V-14.

g. Record the pressure and temperature in the gas cylinder (TC-5, G-2), and note the G-3 pressure.

h. Open V-22.

i. Admit gas, using V-14 or V-23 to maintain the pressure below 50 psi at G-3, or at a pressure less than 50 psi above the propellant-system pressure.

j. Adjust the flow by timing the pressure reduction in the gas cylinder.

k. When the cylinder pressure reaches the predetermined range, close V-14 and/or V-23 and then V-22.

l. Record the pressure and temperature on TC-5, G-2, and G-3.

m. Close all open valves.

n. Repeat the foregoing steps as necessary to add additional contaminant.

4.6 Shutdown Procedure

a. Open V-17, V-16, and V-14 to vent the piping assemblies. Optional: Purge all lines with inert gas if a corrosive, toxic, or combustible contaminant gas was used.

b. Disassemble the unit in reverse order, using appropriate safety measures.

c. Clean all assemblies, using the appropriate cleaning schedule (Ref. 2).

d. Dry all components and store them in a dust-tight enclosure.

4.7 Calculations

4.7.1 Methods and Accuracy

Gas addition measured by pressure and temperature change is subject to substantial error if corrections are not made for the deviations of gas properties from those of an ideal gas. These deviations are condensed into a compressibility factor that varies with temperature and pressure and is different for each gas. Tables of compressibility factors for many gases are available over a wide range of temperature and pressure conditions. A standard source of such data is Ref. 3.

An alternative method of computation consists of calculations using the tabulated properties of the superheated gases. These values may also be found in Ref. 3 for many gases - including methane, carbon dioxide, and nitrogen, which are the gases presently of interest. Because tabulated data for

superheated gases are available in more complete form over the pressure and temperature ranges concerned, this method is described below.

Interpolation, or the selection of data points between points given in the tables, is very reliable and provides answers that should not deviate by more than about 3%. Extrapolation, or extension of the data beyond the table, must be performed with care, because the data are not necessarily linear when plotted. This may be seen in Figure 20, where the volumes of superheated methane, carbon dioxide, and nitrogen at constant temperature are plotted against pressure.

Figure 20 was developed on the basis of data in Ref. 3 and may be used for calculations over the pressure range given. When more-extreme pressures are involved, the original tables in Ref. 3 are recommended for either compressibility or superheating properties.

4.7.2 Initial and Final Pressures to Add Required Charge (Sample Calculation)

The example below is given to demonstrate the calculations required for determination of the required pressures for a given charge. The following conditions are assumed: the addition of 3 lb of methane to a system, an ambient temperature of 100°F, and a cylinder volume of 1.55 cu ft.

The initial cylinder pressure required is determined as follows: The specific volume is given by

$$v = \frac{1.55 \text{ cu ft}}{3 \text{ lb}} = 0.517 \text{ cu ft/lb}$$

From Figure 20, at 100°F for methane, 0.517 cu ft/lb corresponds to 675 psia or 660 psig, whereupon the minimum initial pressure is 660 psi.

To ensure sufficient pressure to maintain a desired addition rate and to exceed the propellant-vessel pressure, an initial pressure is selected that is slightly higher than the sum of the calculated and the propellant-vessel pressure (e.g., 750 psia).

The final pressure corresponding to a 3-lb charge is determined as follows. The actual initial weight is given by

$$w_i = \frac{1.55}{v_{750}}$$

where v_{750} is the specific volume at 750 psia. From Figure 20, v_{750} is 0.466 cu ft/lb at 100°F. Then,

$$w_i = \frac{1.55}{0.466} = 3.33 \text{ lb}$$

The final cylinder weight is given by

$$w_f = 3.33 - 3.0 = 0.33 \text{ lb}$$

The final specific volume is given by

$$v_f = \frac{1.55}{0.33} = 4.69 \text{ cu ft/lb}$$

From Figure 20, at 100°F, 4.69 cu ft/lb corresponds to a final pressure (p_f) of 79.5 psia, or 64.5 psig. The cylinder will therefore initially be pressurized to 735 psig and gas will be introduced to the system until the cylinder pressure reaches 64.5 psig.

A correction is made for the final gas temperature as follows: As gas under high pressure is released, the remaining gas in the cylinder will be cooled. The final cylinder temperature will depend on the rate of gas release and other factors; if necessary, it may be calculated approximately by the use of Joule-Thomson coefficients from Ref. 3.

It is assumed that the final gas temperature is 60°F. From Figure 20, the specific volume at 60°F and 79.5 psia is 4.33 cu ft/lb. The actual weight of gas remaining is then

$$w_f = \frac{1.55}{4.33} = 0.357 \text{ lb}$$

The actual gas weight added to the propellant vessel is

$$\Delta w = w_i - w_f = 3.33 - 0.357 = 2.97 \text{ lb}$$

4.7.3 Charging of Gases at High Pressures (Sample Calculation)

For charges at pressures exceeding the limits of Figure 20, the tables of superheated-gas properties may be used. The only significant difference is that additional calculations are required for interpolation and that conversion of units for nitrogen is necessary.

The sample calculation used above will indicate procedures and also permit a check on the accuracy of Figure 20. As in the foregoing sample, the conditions assumed include the addition of 3 lb of methane, an ambient temperature of 100°F, and a cylinder volume of 1.55 cu ft.

The minimum initial pressure is determined as follows: The initial volume is

$$v = \frac{1.55}{3.0} = 0.517 \text{ cu ft/lb}$$

From Ref. 3 (Table 227, p. 270), 0.517 cu ft/lb lies between 0.712 cu ft/lb at 500 psia and 0.432 cu ft/lb at 800 psia. Interpolating for the minimum pressure, p_{min},

Cu ft/lb	Pressure
0.712	500 psia
0.517	p_{min}
0.432	800 psia

it is found that

$$p_{min} = 800 - \frac{0.517 - 0.432}{0.712 - 0.432} (800 - 500)$$

$$= 709 \text{ psia} = 694 \text{ psig}$$

Hence, 750 psia will be used as the initial pressure so that the final pressure after charging exceeds the pressure in the propellant tank.

The final pressure, p_f, corresponding to a 3-lb charge is determined as follows: The actual initial weight is given by

$$w_i = \frac{1.55}{v_{750}}$$

From Table 227 of Ref. 3 and by interpolation, v_{750} is 0.479 cu ft/lb. Then,

$$w_i = \frac{1.55}{0.479} = 3.24 \text{ lb}$$

The final cylinder weight is given by

$$w_f = 3.24 - 3.0 = 0.24 \text{ lb}$$

Then, the final specific volume is

$$v_f = \frac{1.55}{0.24} = 6.47 \text{ cu ft/lb}$$

By interpolation in Table 227 of Ref. 3,

$$p_f = 58.3 \text{ psia} = 43.3 \text{ psig.}$$

The deviation of the method developed in paragraph 4.7.2 is checked as follows: From Table 227 of Ref. 3, at a p_f of 79.5 psia, v_f is 4.65 cu ft/lb. Then,

$$w_f = \frac{1.55}{v_f} = 0.33 \text{ lb}$$

The actual gas weight added to the propellant vessel is

$$\Delta w = 3.24 - 0.33 = 2.91 \text{ lb}$$

$$\text{Deviation} = \frac{3.0 - 2.91}{3.0} (100) = 3\%$$

4.7.4 Correction for Gas in Piping (Sample Calculation)

In the addition of gaseous contaminants, the volume of the gas cylinder and of piping system up to V-14 and V-23 is included in the calibrated volume.

If the pressure between V-14, V-23, and V-22 is different at the beginning and end of the addition, a correction must be made for the differing amounts of gas remaining in this space. When small quantities of gas are being charged, this residual quantity may be significant. The following conditions are assumed: The initial gas pressure is 5 psig (20 psia) between V-14 and V-22, the final gas pressure is 45 psig (60 psia) on Gage G-3, the cylinder temperature is 60°F, and the gas charged is methane. Then,

$$\Delta w = \Delta w_a - (w_f - w_i)$$

where

Δw = actual weight of gas charged
Δw_a = apparent weight charged, from cylinder-pressure measurements
w_f = weight of gas between V-14 and V-22 at end of charge
w_i = weight of gas between V-14 and V-22 at start of charge

and the volume of the piping between V-14 and V-22 is 0.266 liter, or 0.266/28.32 = 0.0094 cu ft. From Table 227 of Ref. 3, the final specific volume, v_f, is 5.75 cu ft/lb at 60 psia and 60°F. Then,

$$w_f = \frac{0.0094}{5.75} = 0.00163 \text{ lb} = 0.740 \text{ g}$$

It is apparent that if 3 lb had been charged, as in the previous examples, no correction would have been necessary. If the charge had been in the minimum range, the correction would be important. To determine the actual correction, w_i is calculated as follows: The initial specific volume, v_i, is 18.70 cu ft/lb at 5 psig (20 psia) and 100°F. Then,

$$w_i = \frac{0.0094}{18.70} = 0.00050 \text{ lb} = 0.227 \text{ g}$$

If the initially calculated charge had been 2.97 lb as in paragraph 4.7.2, foregoing, the actual weight charged would have been

$$\Delta w = 2.97 - (0.00163 - 0.0005) = 2.97 \text{ lb}$$

If the initially calculated charge had been on the minimum side, say 3 g, the actual weight charged would have been

$$\Delta w = 3.0 - (0.740 - 0.227) = 2.48 \text{ g}$$

and an error of about 20% would have occurred if no correction had been applied.

4.7.5 Correction for Gas in Condenser (Sample Calculation)

When a gas is condensed and the resulting liquid is added to the propellant vessel, a correction may be necessary for the quantity of vapor remaining in the condenser. The following conditions are assumed: The gas charged is methane (refrigerant, liquid methane), the final gas pressure in the condenser is 5 psig or 20 psia, and the volume of the condenser and associated piping is 9.87 liters or 0.3485 cu ft. Inasmuch as the residual methane vapor would be in equilibrium with liquid methane, Table 226 (p. 265) of Ref. 3 is used. By interpolation, v_f is 6.82 cu ft/lb at 20 psia. The weight of gas left is

$$w_f = \frac{0.3485}{6.82} = 0.0512 \text{ lb} = 23.2 \text{ g}$$

Had the condenser been evacuated when the gas-cylinder pressure and temperature were read, 23.2 g would be subtracted from the apparent weight of gas charged. If, instead, the condenser had been pressurized with methane, the difference would have to be subtracted, as in paragraph 4.7.4.

This correction applies when liquid methane is the refrigerant. Had LN_2 been used as the refrigerant, essentially all the methane would have been condensed because of the lower temperature (-320°F at 15 psia) and no correction would be necessary, assuming that the liquid is forced into the propellant tank by pressurizing with an inert gas.

5.0 Cryogenic-Liquid-Addition Unit

5.1 Description

Condensed gases may be added to a vessel containing liquid propellants. Charging is by pressurized transfer from a condenser, employing the vapor pressure of the contaminant for the introduction of large quantities and inert-gas pressure for small quantities. The contaminant is measured by means of pressure and temperature differential in the three calibrated cylinders, as for gaseous-contaminant introduction (Section 4.0). The unit is shown schematically in Figure 14. The quantity charged is dependent on the initial cylinder pressure; the rate is controlled by manually operated valves.

5.2 Equipment

The three gas cylinders described in paragraph 4.2 are used. Their capacities are approximately 44, 4, and 0.4 liters, and they are equipped with copper-constantan thermocouples for gas-temperature measurement. Equipment used to introduce gases into the condenser and to make measurements is described in paragraph 4.2.

A 9-liter, double-wall, insulated condenser is provided for contaminant quantities of 1 lb or greater. The condenser jacket is equipped with fittings for the introduction of a refrigerant, such as LN_2, and for venting the vaporized refrigerant. The venting can be against atmospheric pressure or, more normally, against a 100-psig relief valve. The condenser is provided with fittings to connect to the center spray nozzle on the charging flange.

Smaller quantities of liquefied-gas contaminants are added through a continuous-condensing coil fitted within a jacket to contain, typically, LN_2 as a refrigerant. An inert-gas purge line is provided to inject the condensate into the propellant vessel. The condensate line is connected to the spray nozzle in the charging flange through a tee.

5.3 Preparation

The gas cylinders, valves, piping, and condensers must be clean to a degree commensurate with the contaminant and propellant in use. For cryogenic

use, no water vapor is permissible in either the condenser or the jacket, because the nozzles, check valves, or other apertures might become clogged.

The unit is precalibrated, and no additional calibration is required unless piping changes are made. The volume of gas delivered is determined from the instrument readings as outlined in paragraph 4.7. Because the pressure measurements are critical with regard to accuracy in the use of this unit, all pipe and tube fittings must be leak-tight over the pressure range in use.

5.4 Setup Procedure (See Figures 14 and 15)

a. Connect the support brackets to the charging-flange lifting lugs.

b. Mount the condensers on brackets and connect the condensate line to the spray nozzle on the charging-flange cover.

c. Connect Piping Assembly B to the inlet provided for contaminant gas.

d. Connect Piping Assembly A to the gas cylinder to be used.

e. Connect Assemblies A and B with 1/2-in. tubing (supplied).

f. Connect Piping Assembly C to Assembly B.

g. Connect the coolant vent.

h. Connect the refrigerant line to the copper coil around V-8.

i. Connect the contaminant-gas source to V-13.

j. Connect the vacuum line to V-17.

5.5 Operation

5.5.1 System Preparation

a. Close all valves.

b. Open V-12, V-14, V-16, V-32, V-33, and V-29, and evacuate through V-17.

c. Close V-14 and V-17.

d. Open V-13 and pressurize the tank to the required value.

e. Close V-13.

5.5.2 Jacket Purge

a. Connect the dry inert-gas source to V-18.

b. Close V-27 and V-30, and purge through V-19 for 5 min.

c. Close V-19, and purge through V-20 at 100 psi for 1 min.

d. Open V-27, and purge for 5 min; close V-27.

e. Open V-30 and V-31, and purge for 5 min; close V-30 and V-31.

f. Connect the refrigerant in place of the inert gas.

5.5.3 Cooldown Procedure

a. Open V-19 and V-34.

b. Introduce refrigerant into the jacket through V-18 or V-31 as appropriate, and to the condensate cooling coil.

c. When liquid refrigerant appears at V-34, close V-34.

d. When liquid appears at the V-19 coolant vent, the condenser is full; close V-19.

e. Close V-18 or V-31 as appropriate.

5.5.4 Operation of Large Condenser

a. Close V-32, read the pressure at G-2, and check G-3.

b. Partially open V-14 or V-23, and maintain a pressure at G-3 approximately 50 psi greater than the propellant-vessel pressure.

c. When the proper amount of contaminant gas has condensed as indicated at G-2, close V-14 or V-23.

d. Record the cylinder pressure and temperature.

e. Wait until the pressure at G-4 equals the pressure at G-3 or until the pressure at G-3 exceeds the pressure in the propellant-storage vessel.

f. Open V-8. It may be necessary to drain the refrigerant at V-27 to develop an adequate pressure if the boiling point of the refrigerant is substantially below that of the contaminant.

g. When the pressure at G-3 begins dropping rapidly, close V-8.

h. Read the pressure at G-3.

i. Calculate the amount of contaminant gas added by the method of paragraph 4.7.

5.5.5 Operation of Small Condenser

a. Close V-33 and V-29.

b. Pressurize the piping with contaminant gas through V-14 or V-23; close V-14 and V-23.

c. Read the pressures at G-3 and G-2 and the temperature at TC-5.

d. Open V-8.

e. Add contaminant gas through V-14 or V-23 at a rate not to exceed 0.1 lb gas/min.

f. When the desired amount of contaminant gas has been added, close V-14 and V-23.

g. Close V-16; read the pressures at G-3 and G-2 and the temperature at TC-5.

h. Purge the condensing coil with inert gas or recycled propellant through V-17 or V-7.

i. Close V-8.

5.6 Shutdown Procedure

a. If recycled propellant was used to purge the condenser coils, residual propellant may be forced into the storage vessel by pressurization with inert gas.

b. Purge all the lines with inert gas if a corrosive, toxic, or combustible contaminant gas was used.

c. Relieve the pressure by disconnecting the inert-gas line at V-17 and opening the valve.

d. Disassemble the unit in reverse order, using appropriate safety measures.

e. Clean all assemblies, using the appropriate cleaning schedule (Ref. 2).

f. Dry all components and store them in dust-tight enclosures.

6.0 Solids-Addition Unit

6.1 Description

The solid-contaminant-addition unit is designed to permit the charging of known quantities of fine granular solids such as silica or iron oxide to the propellant-supply vessel. The charging is by the batch method; the

quantity may be varied from 0.2 to 9.6 g of materials such as sand. Measurement is volumetric, and the weight charged therefore varies with the density. Larger amounts may be charged by repeating the batch charges. The assembly is shown in Figure 19.

6.2 Equipment

The solids-metering device is the microsetting powder measure manufactured by the Santa Anita Engineering Company. The piping consists of two ball valves, a mounting bracket, and purge lines as shown in Figures 18 and 19. The piping assembly is mounted on the 3/4-in. union on the charging-flange cover. The powder measure is mounted on the bracket that is bolted to the charging-flange lifting lug. Charging is accomplished by closing the lower ball valve, opening the upper ball valve, mounting the powder measure, and turning the powder-measure handle for the required number of cycles to add the amount desired. The powder measure is then removed, the upper ball valve is closed, and the lower ball valve is opened. The solids are washed into the vessel either by the recycled propellant or by an inert-gas purge, as desired. If the recycle stream is toxic, inert gas should be introduced through the ball-valve system for several seconds before a second charge of solids is added. The valves are then closed. Residual vapors may be present in this zone; therefore, the upper valve should be opened with care when the unit is again opened.

6.3 Preparation

The piping and the powder measure must be clean to the degree necessary for the particular combination of propellant and contaminant to be used. The cleaning procedures will vary according to the propellant used and are established for each propellant. No lubrication is to be used in this system.

The microsetting powder measure will provide consistent charges of solids when the solids have been compacted uniformly in the hopper of the powder measure. To prepare the powder measure for use, the drum applicable to the quantity of solids to be charged is selected. The small drum has a sand capacity varying from approximately 0.2 to 2.3 g/cycle, and the large-drum capacity varies from 1.2 to 9.6 g/cycle. The drum must be adjusted and calibrated prior to use. The cylinder is filled with solids and is rapped eight times with the attached hammer. The first five charges are discarded after rapping the cylinder twice at the top of the handle stroke and twice at the bottom of the stroke. A charge is delivered and weighed. The number of times the cylinder is to be rapped with the hammers is not critical, but a consistent procedure should be followed throughout the calibration and charging steps. The drum volume should be adjusted if necessary to provide an even fraction of the desired total charge, and should then be recalibrated as outlined above.

6.3 Setup Procedure (See Figures 18 and 19)

a. Attach the valve and tee assembly.

b. Connect the inert-gas purge line to V-17.

c. Connect the propellant-recycle line to V-7, if required. (Note: if the solids chamber is to be evacuated to prevent admission of air to the

vessel, the vacuum connection should be made at the upper ball valve after the charge is introduced into the chamber.)

d. Attach the powder-measure mounting bracket to the lifting lug.

e. Calibrate and fill the powder measure.

6.5 Operation

a. Close all valves.

b. Open V-25.

c. Install the powder measure on the mounting bracket.

d. Charge solids from the powder measure by moving the handle up, rapping the chamber twice, and moving the handle down.

e. Remove the powder measure.

f. Close V-25.

g. Optional: Evacuate the chamber at V-25 and close V-25.

h. Optional: Open V-7 to purge with propellant; open V-24, wait 1 min, and close V-7.

i. Open V-17 slightly to pressurize or to purge with inert gas; open V-24 if closed, wait 30 sec, and close V-17.

j. Close V-24.

6.6 Shutdown Procedure

a. Disconnect the line from V-17 and release the pressure in the assembly.

b. Disassemble in the reverse order, using appropriate safety measures.

c. Clean the propellant-piping assembly, using the appropriate cleaning scheduld (Ref. 2).

d. Clean and dry the powder measure.

e. Store the components in dust-tight polyethylene bags.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The contaminant-addition units designed, constructed, and tested in this program have demonstrated the feasibility of adding a variety of

op

contaminants to a vessel containing propellant. Wide ranges of contaminant concentrations may be prepared with accuracies of from 6 to 20%.

The system was designed to be simple and thereby to provide easy operation and maintenance. More elaborate systems with automatic or semi-automatic operations might be desirable for future use.

The contaminant-introduction system was constructed to provide a device for the accurate addition of contaminants. The assembly is a prototype consisting of five units mounted singly on the flange. Conceivably at a future time a single, multifunctional unit would be useful for the simultaneous addition of two or more contaminants.

B. RECOMMENDATIONS

The systems that were constructed in this program are relatively simple, but the operator should keep in mind the specific hazards of the propellants being handled. Cryogenic liquids must never be isolated and allowed to warm without making provision for relief of the pressure that will develop. Pressure-relief valves have been provided, where required, for the manipulation of sample and contaminant, but are not provided between all valves. The operator should be intimately familiar with the operation of each unit before testing begins.

In the addition of contaminant gases to the propellant, the amount of sample charged might be determined by weighing the calibrated gas cylinders with electronic load cells. This method would be faster than the present method, and might assure greater accuracy, but the use of such load cells would be considerably more expensive.

If the contaminant-introduction system is to be used extensively for LF_2 and ClF_3, it is recommended that all-welded or AN-tube connections be used instead of threaded connections. Likewise, for frequent use with corrosive gases and for frequent use in a fixed location, stainless-steel pressure transducers rather than bronze Bourdon tubes are recommended.

LIST OF REFERENCES

1. Prototype Propellant-Testing System, Phases I and II - Feasibility Study and Preliminary Design, RTD-TDR-63-3 (Aerojet-General Report 2452), February 1963.

2. The Handling and Storage of Liquid Propellants, Office of the Director of Defense Research and Engineering, Washington 25, D.C., March 1961.

3. J. H. Perry, Chemical Engineers' Handbook, 3rd ed., pp. 204-207 & 255-273, New York, McGraw-Hill, 1950.

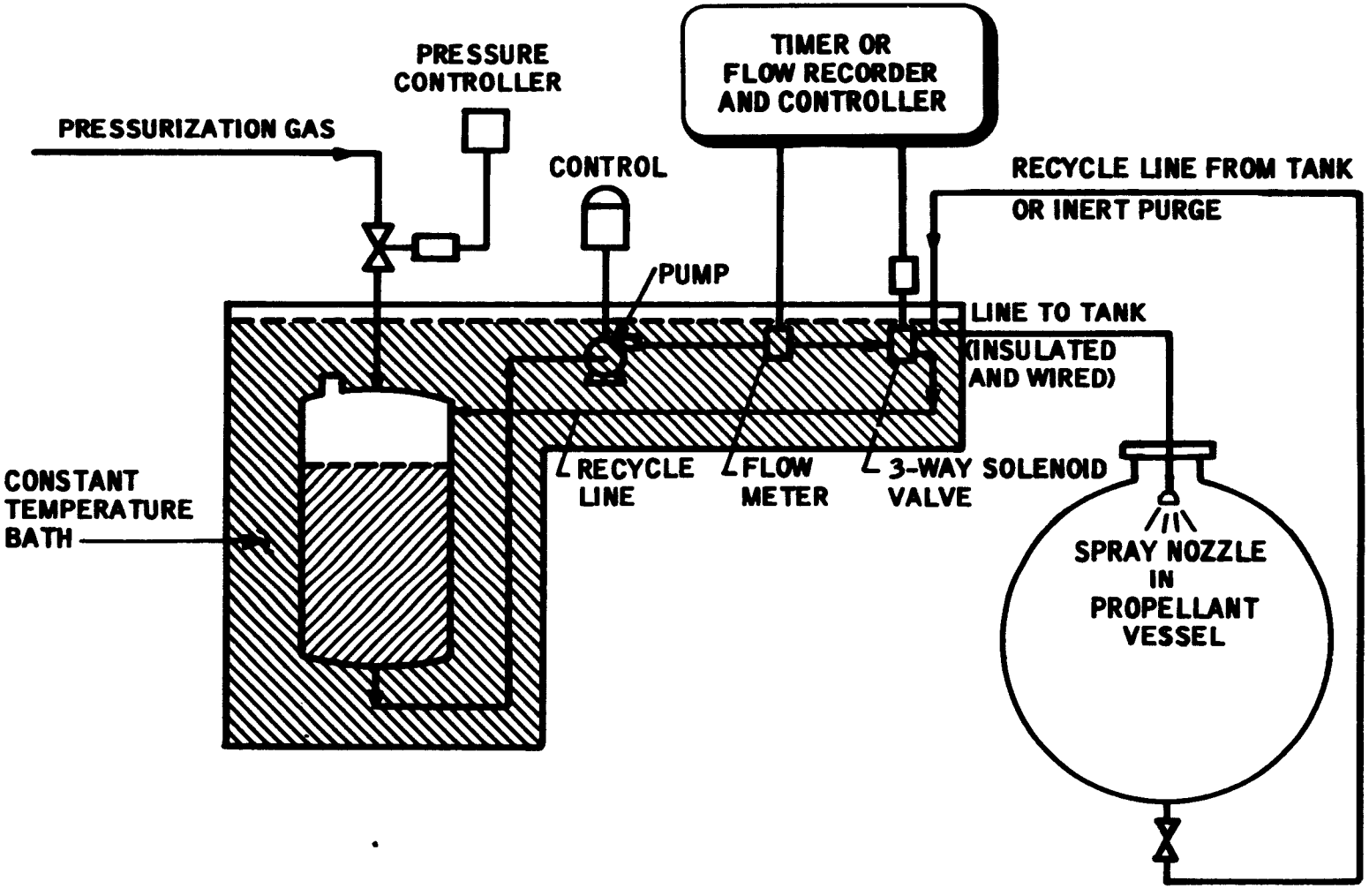


Figure 1

SINGLE SYSTEM FOR METERING OF CONTAMINANTS

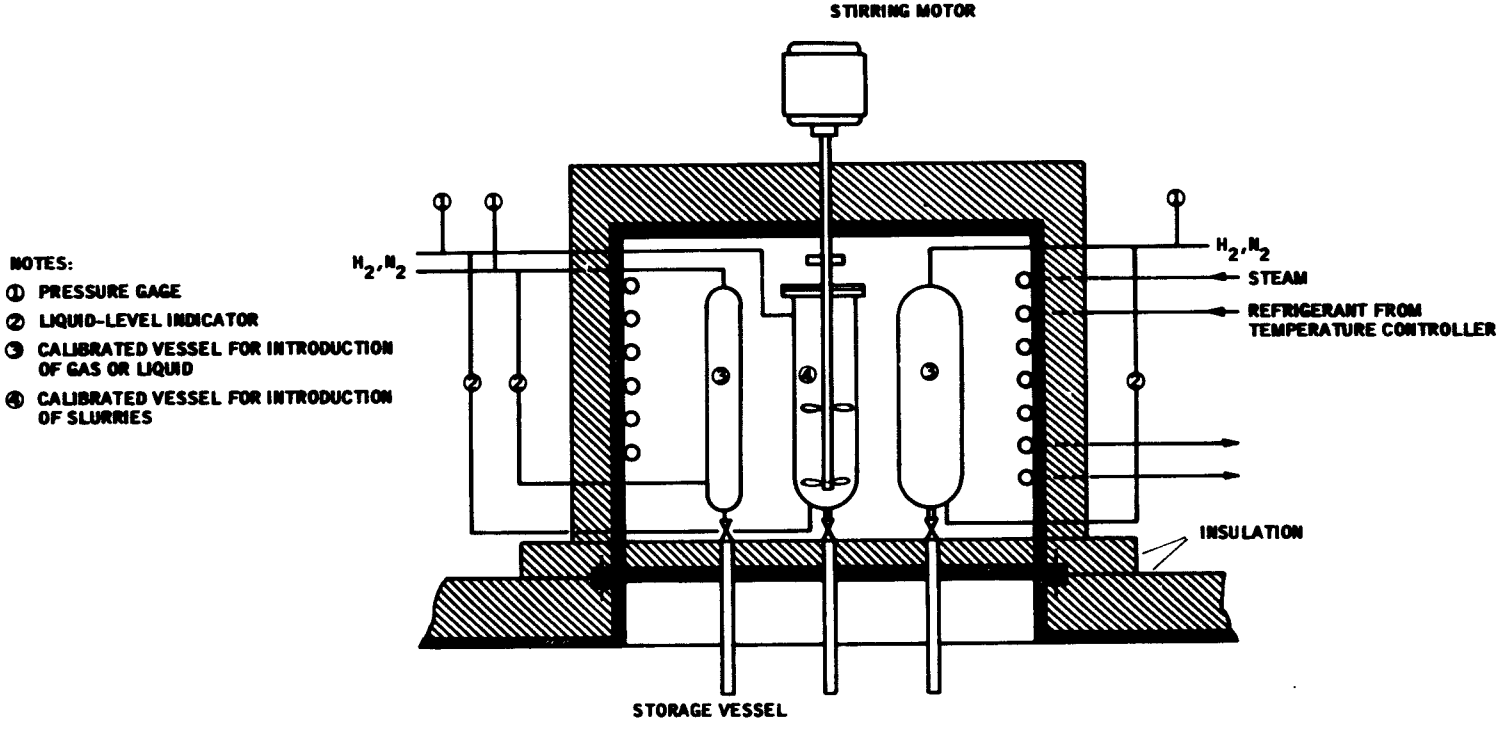
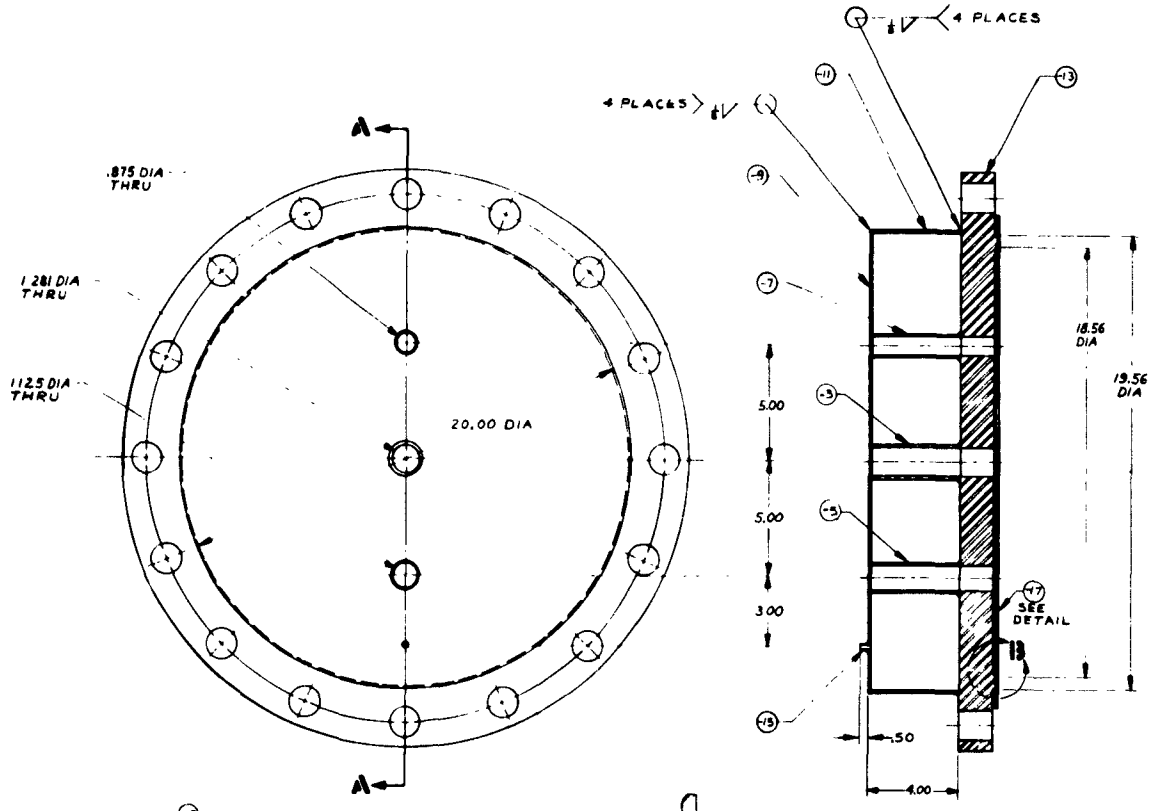


Figure 2

SINGLE SYSTEM FOR ADDITION OF CONTAMINANTS

2. USE INERT GAS SHIELDED TUNGSTEN ARC PROCESS FOR ALL WELDS.
3. CHECK FOR LEAKS WITH G.E. HALOGEN LEAK DETECTOR.
4. GASKET FACE OF MATING FLANGE TO BE IDENTICAL TO DETAIL 13
5. FLANGE BOLTS TO BE TORQUED TO 80 FT. LBS.



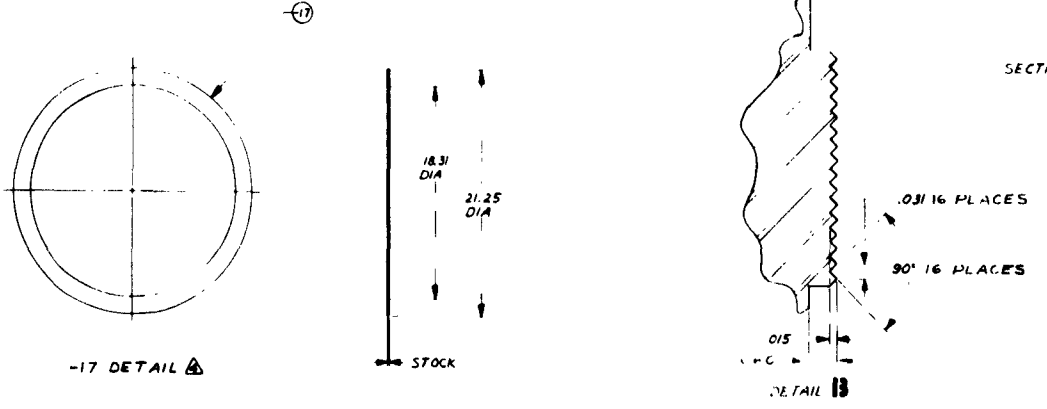


Figure 3

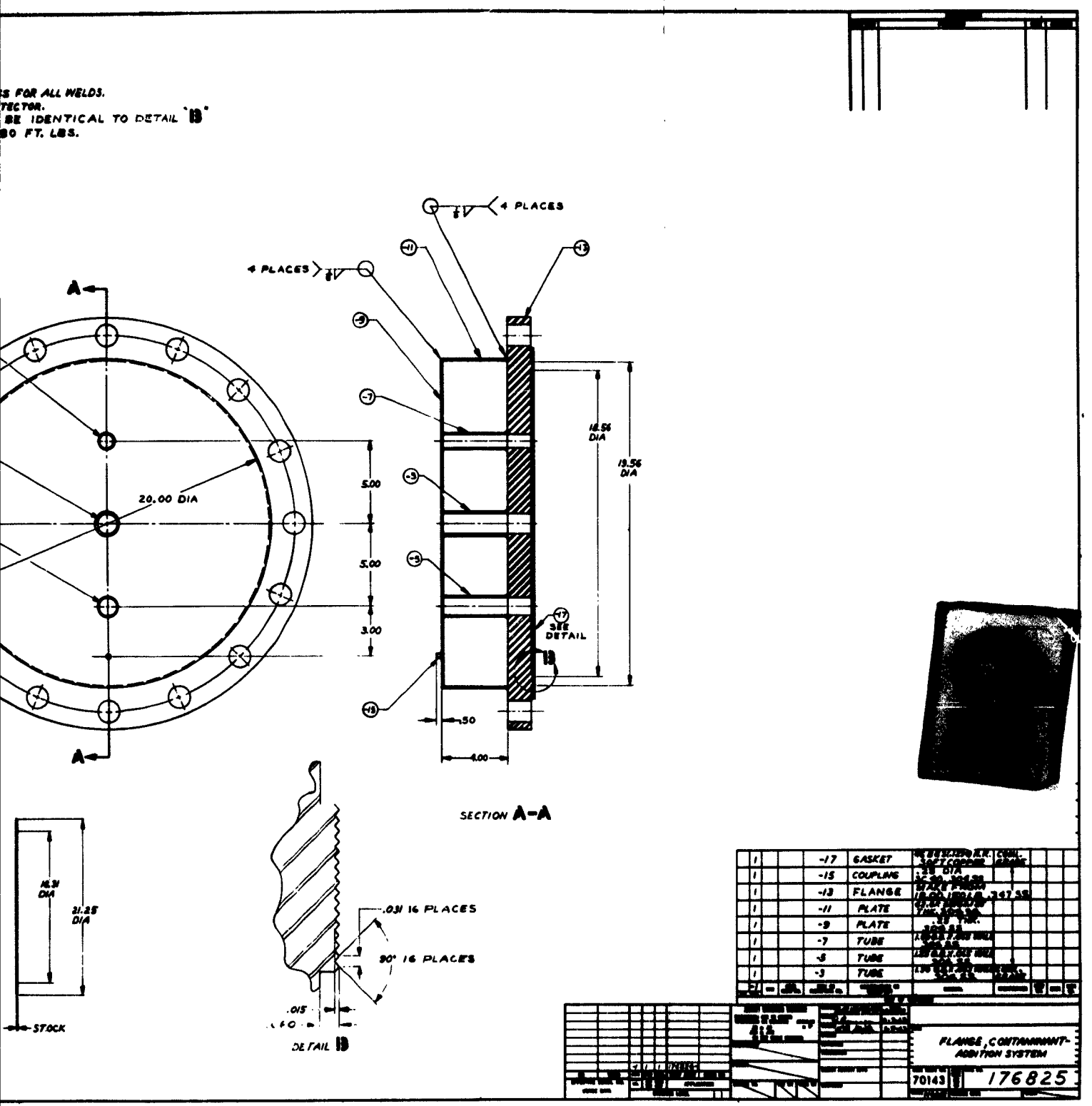

S FOR ALL WELDS.
TECTOR.
SE IDENTICAL TO DETAIL "B"
80 FT. LBS.
4 PLACES
4 PLACES
A
A
20.00 DIA
5.00
5.00
3.00
18.56 DIA
19.56 DIA
SEE DETAIL
.50
4.00
SECTION A-A
16.31 DIA
21.25 DIA
STOCK
.031 16 PLACES
90° 16 PLACES
.015
DETAIL B
-17 GASKET
-15 COUPLING
-13 FLANGE
-11 PLATE
-9 PLATE
-7 TUBE
-5 TUBE
-3 TUBE
FLANGE, CONTAINMENT-
ADDITION SYSTEM
70143
176825

Figure 3

2. ALL WELDS SHALL BE BY INERT-GAS-SHIELDED TUNGSTEN ARC PROCESS.
3. CHECK FOR LEAKS BY BOLTING FLANGE TO PRESSURE VESSEL AND PRESSURIZING TO 200 PSIG. NO LEAKS PERMITTED.

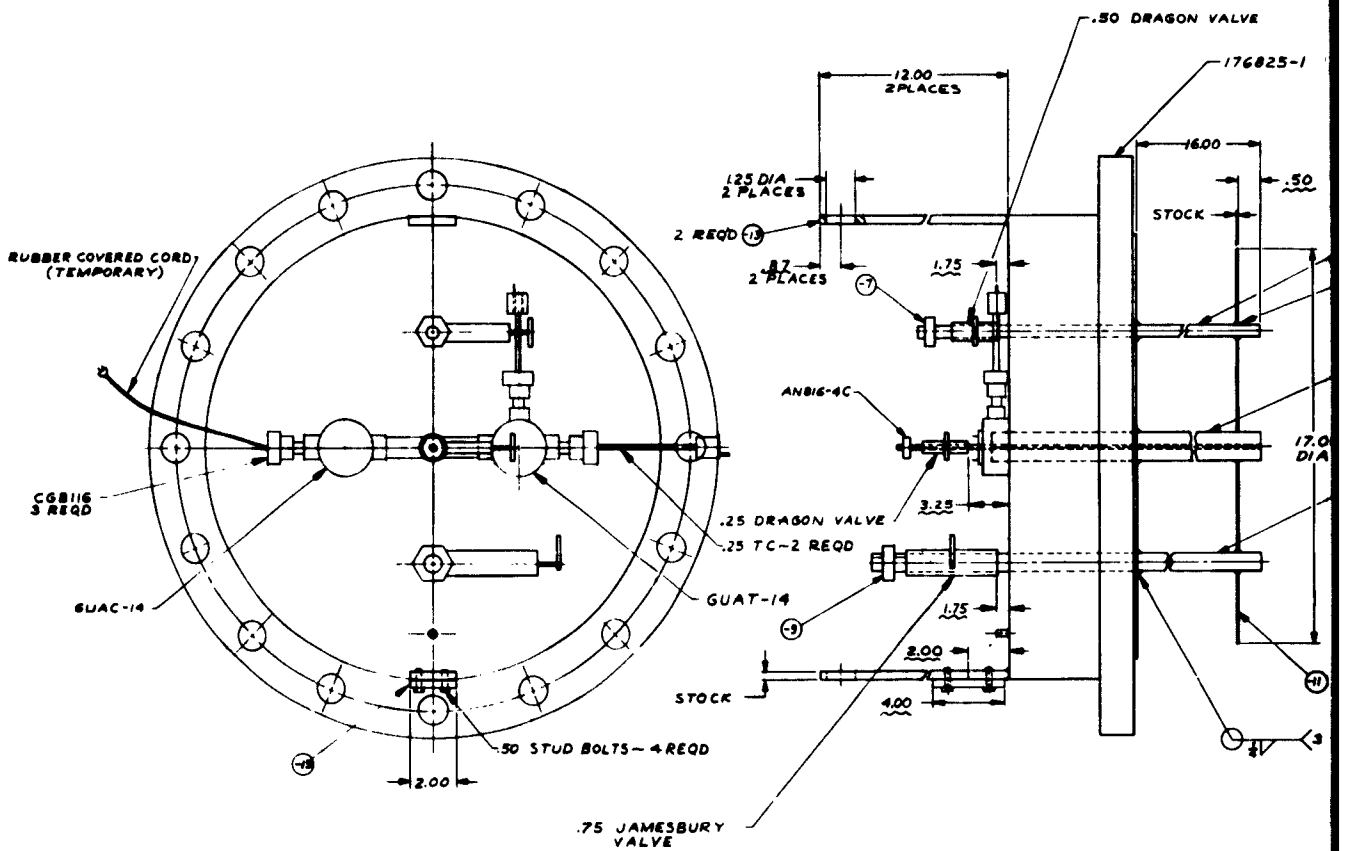


Figure 4

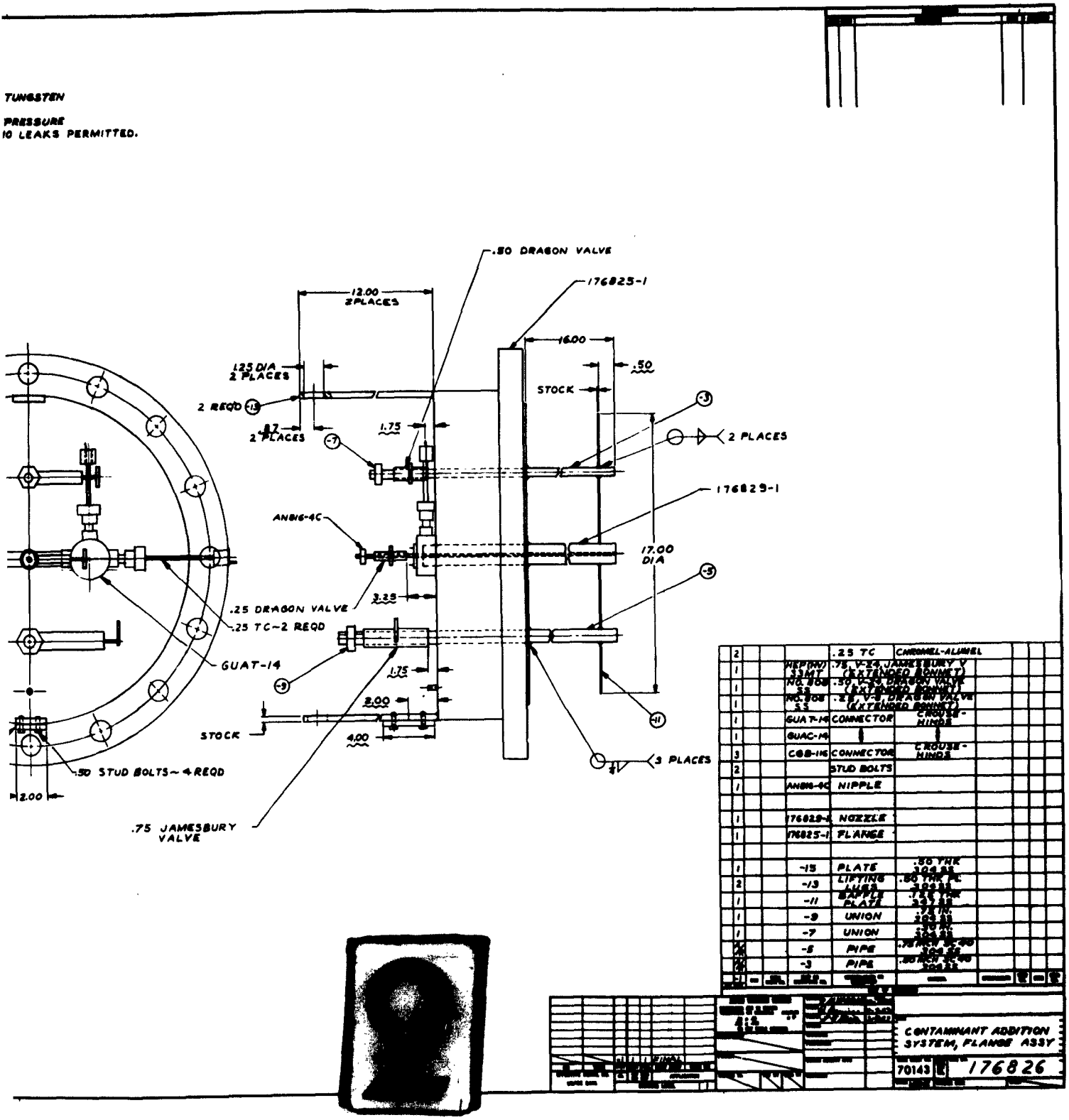

TUNGSTEN
PRESSURE
10 LEAKS PERMITTED.
.50 DRAGON VALVE
176825-1
12.00
2PLACES
16.00
.50
STOCK
.125 DIA
2 PLACES
2 REQD
.87
2 PLACES
1.75
2 PLACES
176829-1
ANB16-4C
17.00
DIA
.25 DRAGON VALVE
3.35
.25 TC-2 REQD
GUAT-14
1.75
2.00
STOCK
4.00
.50 STUD BOLTS-4 REQD
2.00
.75 JAMESBURY
VALVE
3 PLACES
.25 TC
CHROMEL-ALUMEL
.75 V-24 JAMESBURY V
(EXTENDED BONNET)
.50 V-24 DRAGON VALVE
(EXTENDED BONNET)
.25 V-8 DRAGON VALVE
(EXTENDED BONNET)
GUAT-14 CONNECTOR CROUSE-HINDS
GUAC-14
GBB-116 CONNECTOR CROUSE-HINDS
STUD BOLTS
ANB16-4C NIPPLE
176829-1 NOZZLE
176825-1 FLANGE
-15 PLATE .50 THK
-13 LIFTING LUGS .50 THK PL
-11 BAFFLE PLATE .75 THK
-9 UNION
-7 UNION
-5 PIPE
-3 PIPE
CONTAINMENT ADDITION
SYSTEM, FLANGE ASSY
70143
176826

Figure 4

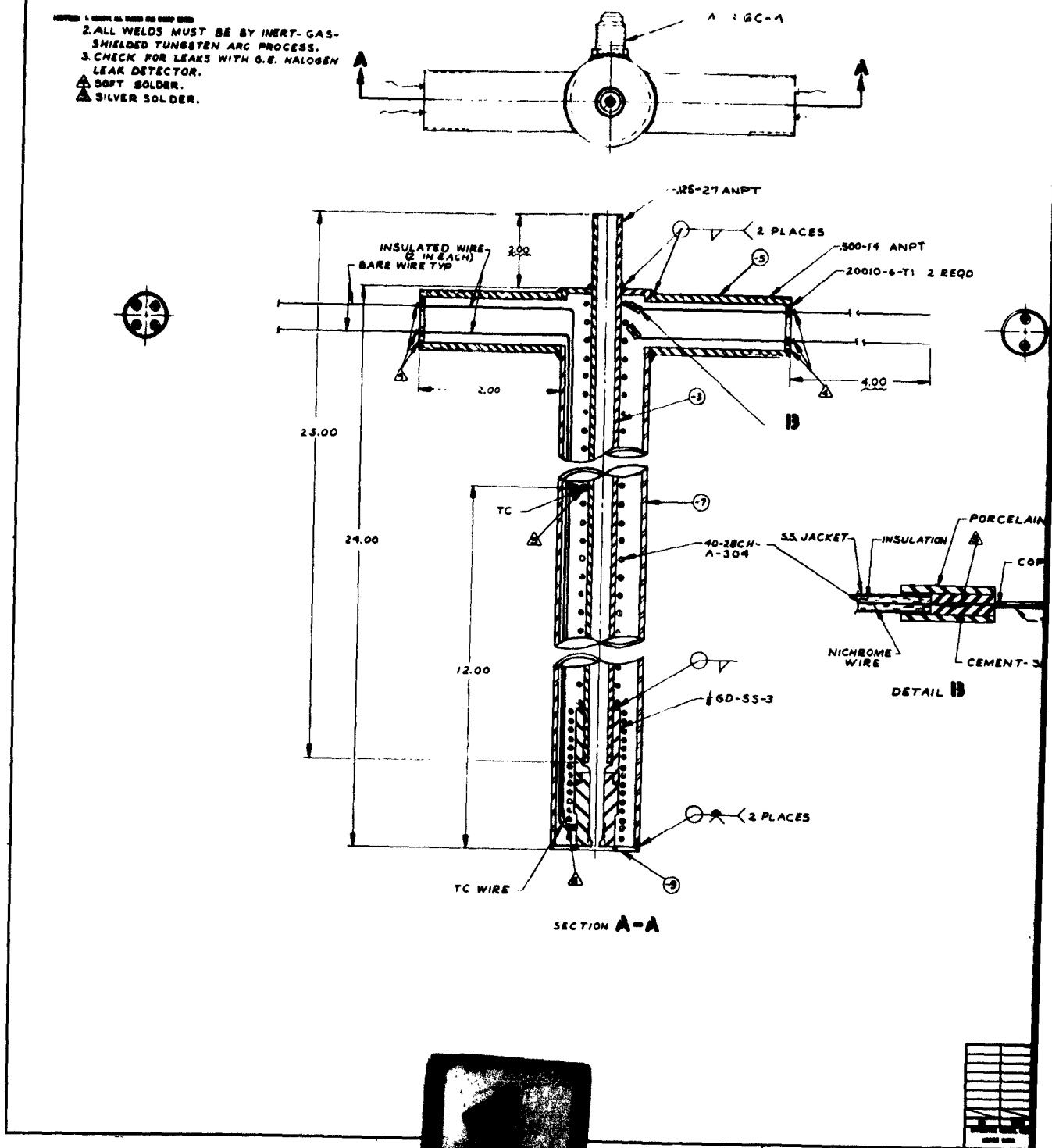

2. ALL WELDS MUST BE BY INERT-GAS-SHIELDED TUNGSTEN ARC PROCESS.
3. CHECK FOR LEAKS WITH G.E. HALOGEN LEAK DETECTOR.
SOFT SOLDER.
SILVER SOLDER.
A
A
.125-27 ANPT
2 PLACES
.500-14 ANPT
20010-6-T1 2 REQD
INSULATED WIRE (2 IN EACH)
BARE WIRE TYP
2.00
2.00
4.00
B
25.00
24.00
12.00
TC
40-28CH-A-304
SS JACKET
INSULATION
PORCELAIN
NICHROME WIRE
CEMENT
DETAIL B
GD-SS-3
2 PLACES
TC WIRE
SECTION A-A

Figure 5

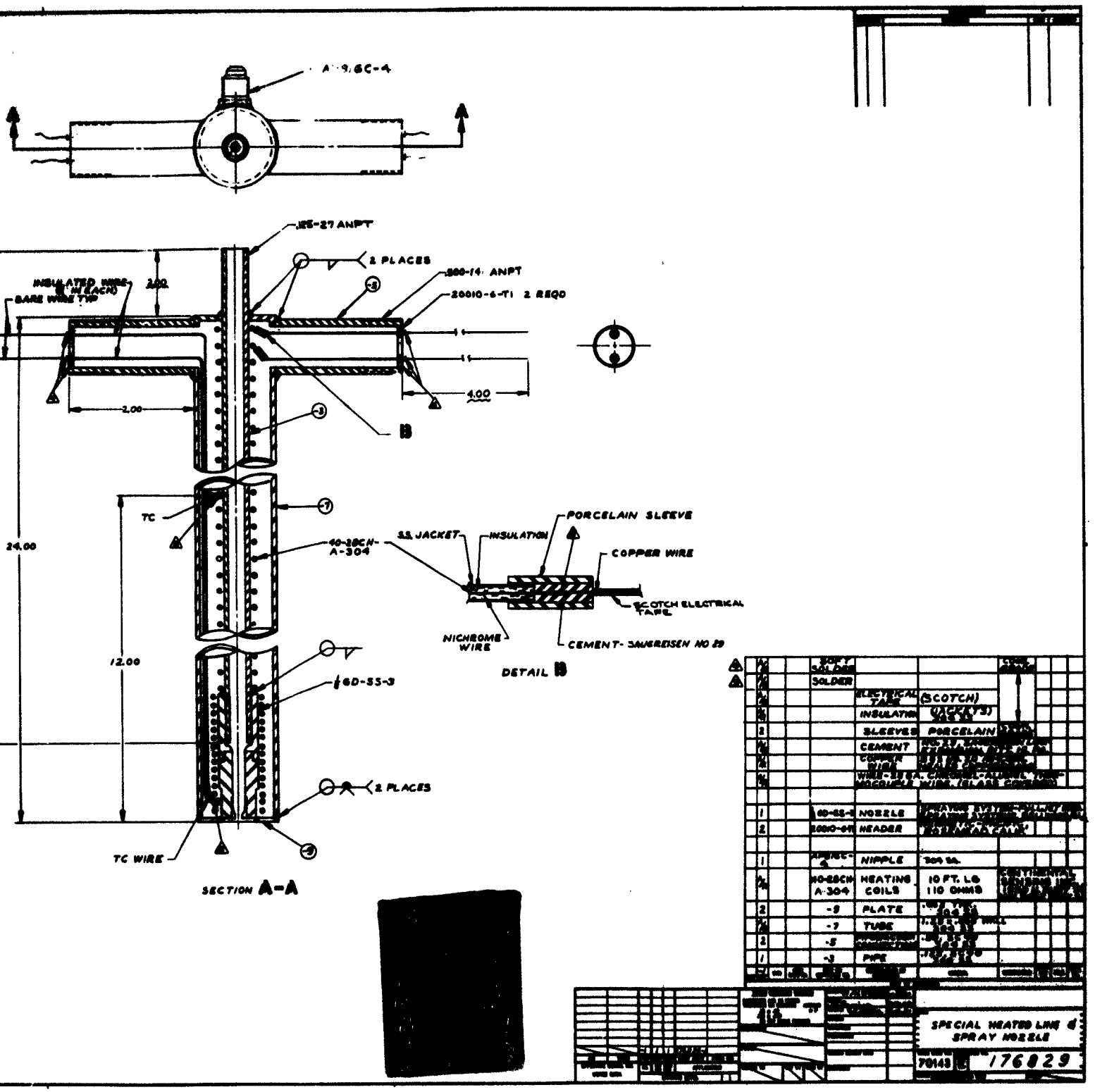
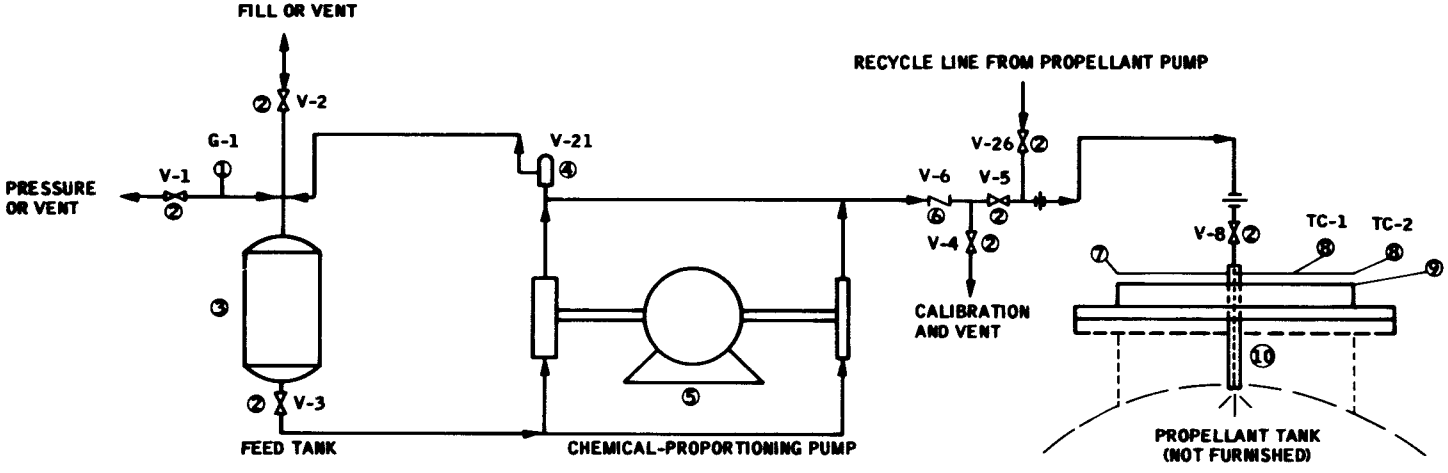

A-9.6C-4
.25-27 ANPT
2 PLACES
.500-14 ANPT
20010-6-T1 2 REQD
INSULATED WIRE (2 REQD)
BARE WIRE TIP
2.00
4.00
2.00
B
TC
24.00
12.00
40-20CH-A-304
SS JACKET
INSULATION
PORCELAIN SLEEVE
COPPER WIRE
SCOTCH ELECTRICAL TAPE
NICHROME WIRE
CEMENT- SAUEREISEN NO 29
DETAIL B
60-SS-3
2 PLACES
TC WIRE
SECTION A-A
SOFT SOLDER
SOLDER
ELECTRICAL TAPE
(SCOTCH)
INSULATION
(GLASS)
SLEEVES
PORCELAIN
CEMENT
COPPER WIRE
NOZZLE
HEADER
NIPPLE
304 SS.
40-20CH A-304
HEATING COILS
10 FT. LG
110 OHMS
PLATE
TUBE
PIPE
SPECIAL HEATED LINE & SPRAY NOZZLE
70143
176829

Figure 5



NOTES:

① PRESSURE GAGE, 0-300 PSIG
② HAND-OPERATED VALVES
③ FEED TANK
④ RELIEF VALVE SET AT 200 PSIG
⑤ CHEMICAL-PROPORTIONING PUMP, 0.04 TO 4 GPH
⑥ CHECK VALVE
⑦ 0-110 VOLT TRANSFORMER, 5 AMP
⑧ THERMOCOUPLES
⑨ SPECIAL VACUUM-JACKETED 18-IN. FLANGE
⑩ SPECIAL HEATED LINE WITH SPRAY NOZZLE

FLOW DIAGRAM FOR LIQUID - CONTAMINANT ADDITION

Figure 6

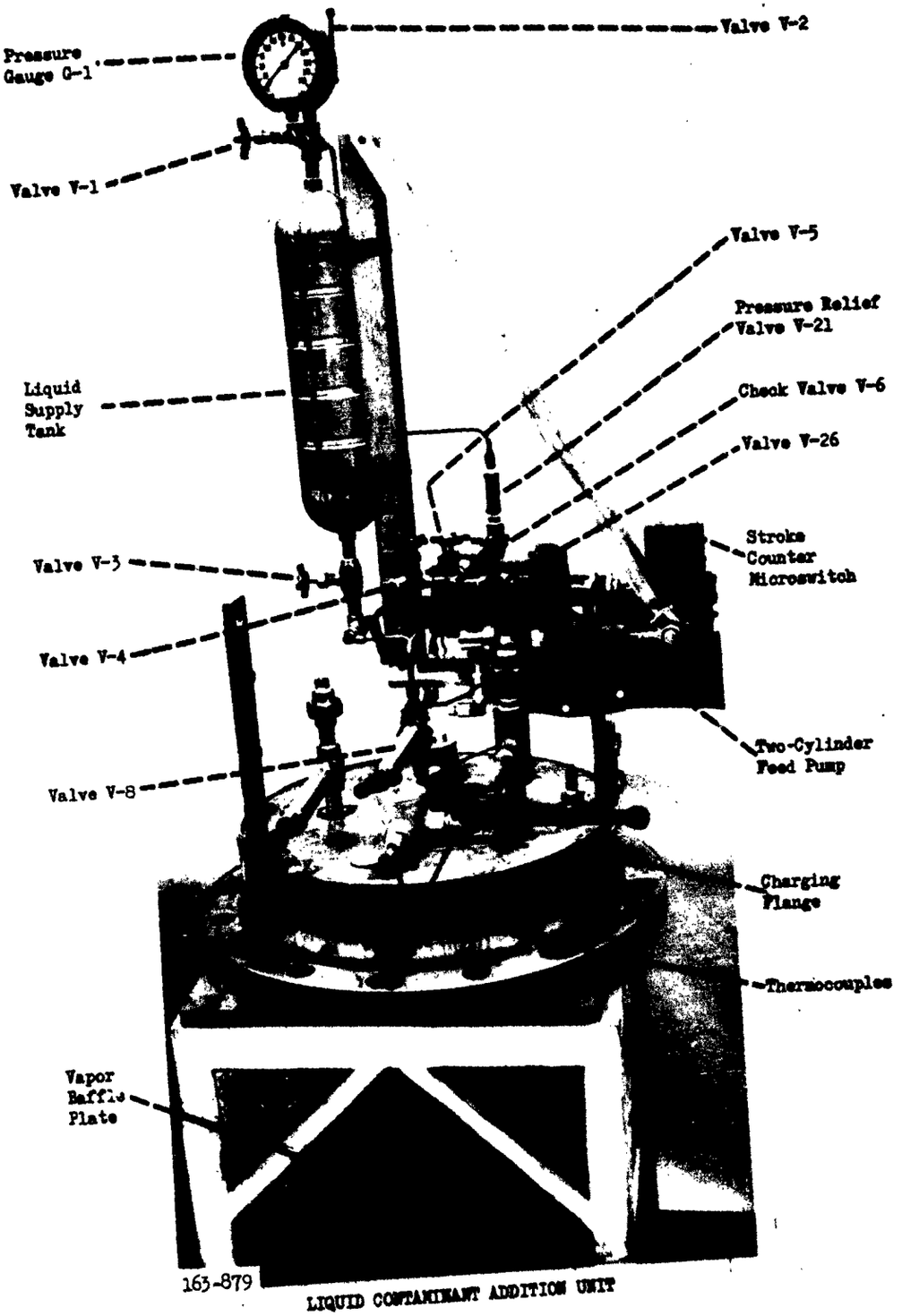

Valve V-2
Pressure Gauge G-1
Valve V-1
Valve V-5
Pressure Relief Valve V-21
Liquid Supply Tank
Check Valve V-6
Valve V-26
Stroke Counter Microswitch
Valve V-3
Valve V-4
Two-Cylinder Feed Pump
Valve V-8
Charging Flange
Thermocouples
Vapor Baffle Plate
163-879
LIQUID CONTAMINANT ADDITION UNIT

Figure 7

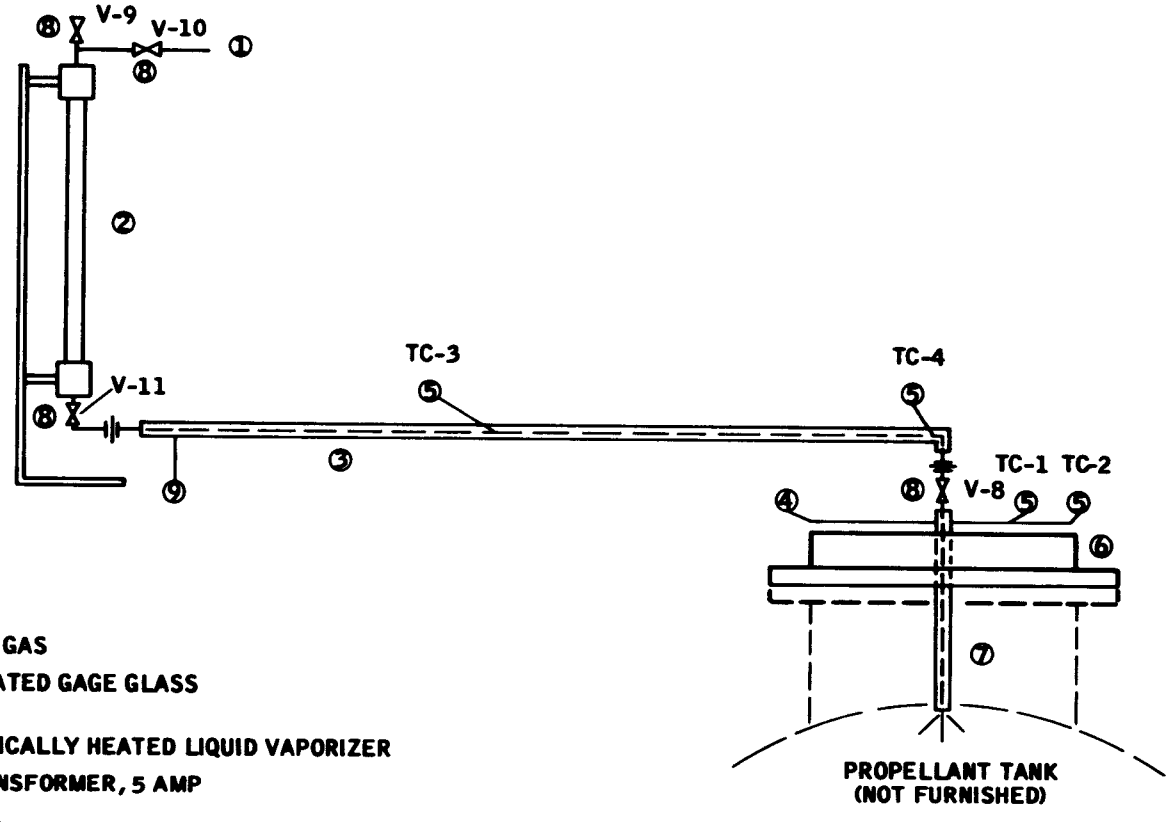


Figure 8

NOTES:

① 0-100 PSI INERT GAS

② SPECIAL CALIBRATED GAGE GLASS WITH SUPPORT

③ SPECIAL ELECTRICALLY HEATED LIQUID VAPORIZER

④ 0-110 VOLT TRANSFORMER, 5 AMP

⑤ THERMOCOUPLES

⑥ SPECIAL VACUUM-JACKETED 18-IN. FLANGE

⑦ SPECIAL HEATED LINE WITH SPRAY NOZZLE

⑧ HAND-OPERATED VALVES

⑨ 0-110 VOLT TRANSFORMER, 10 AMP

FLOW DIAGRAM FOR WATER - VAPOR - CONTAMINANT ADDITION

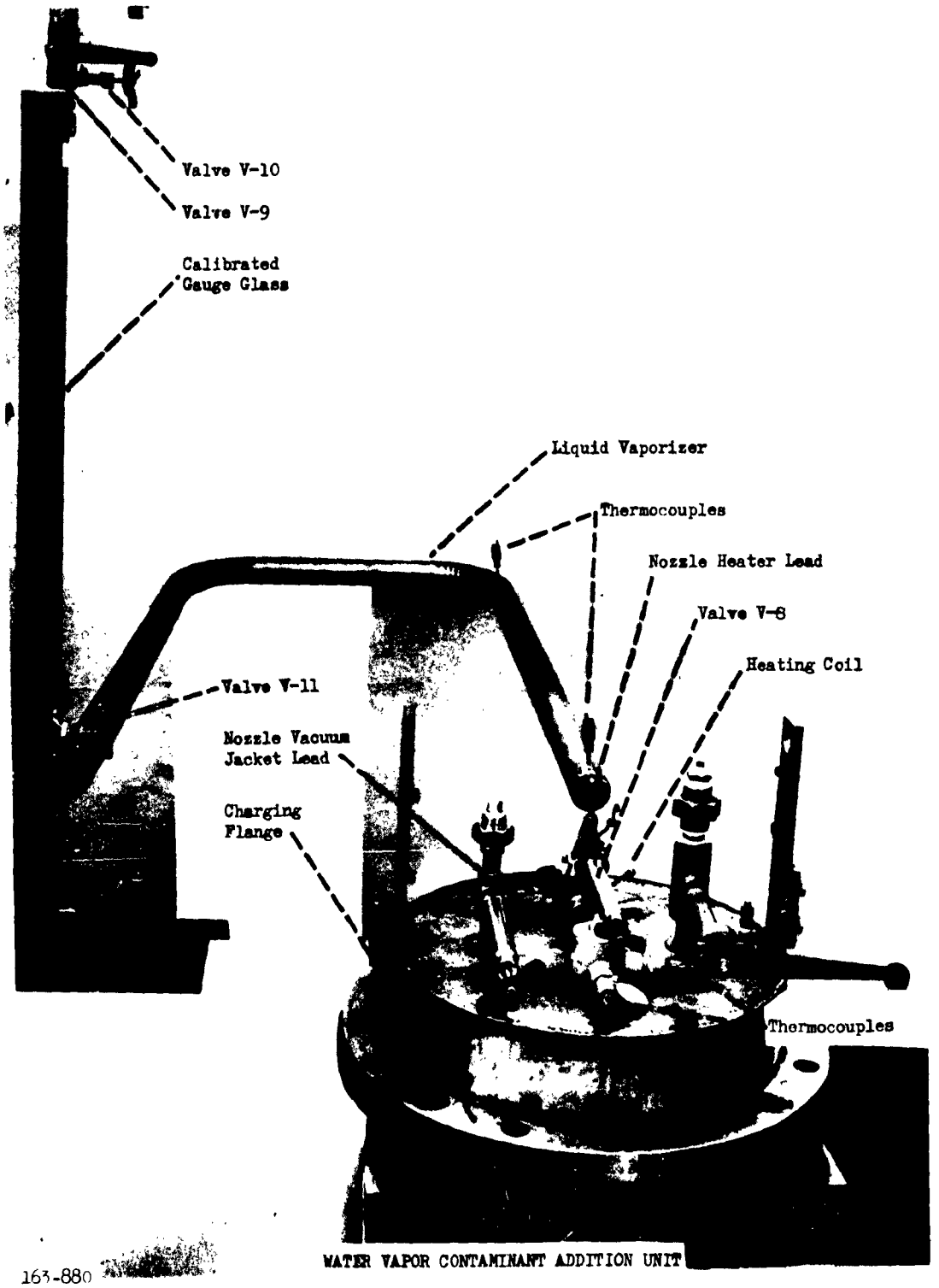

Valve V-10
Valve V-9
Calibrated
Gauge Glass
Liquid Vaporizer
Thermocouples
Nozzle Heater Lead
Valve V-8
Heating Coil
Valve V-11
Nozzle Vacuum
Jacket Lead
Charging
Flange
Thermocouples
163-880
WATER VAPOR CONTAMINANT ADDITION UNIT

Figure 9

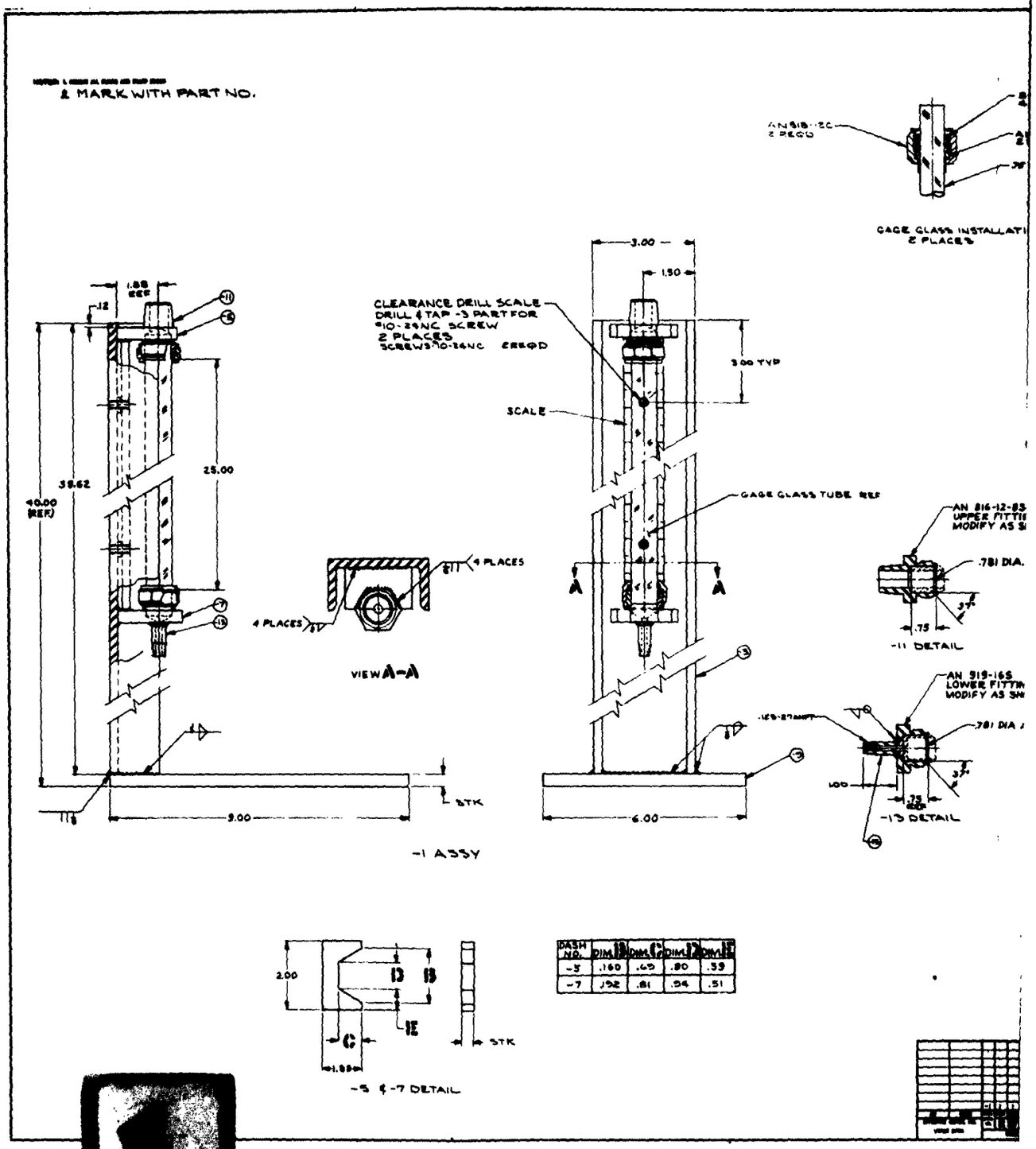
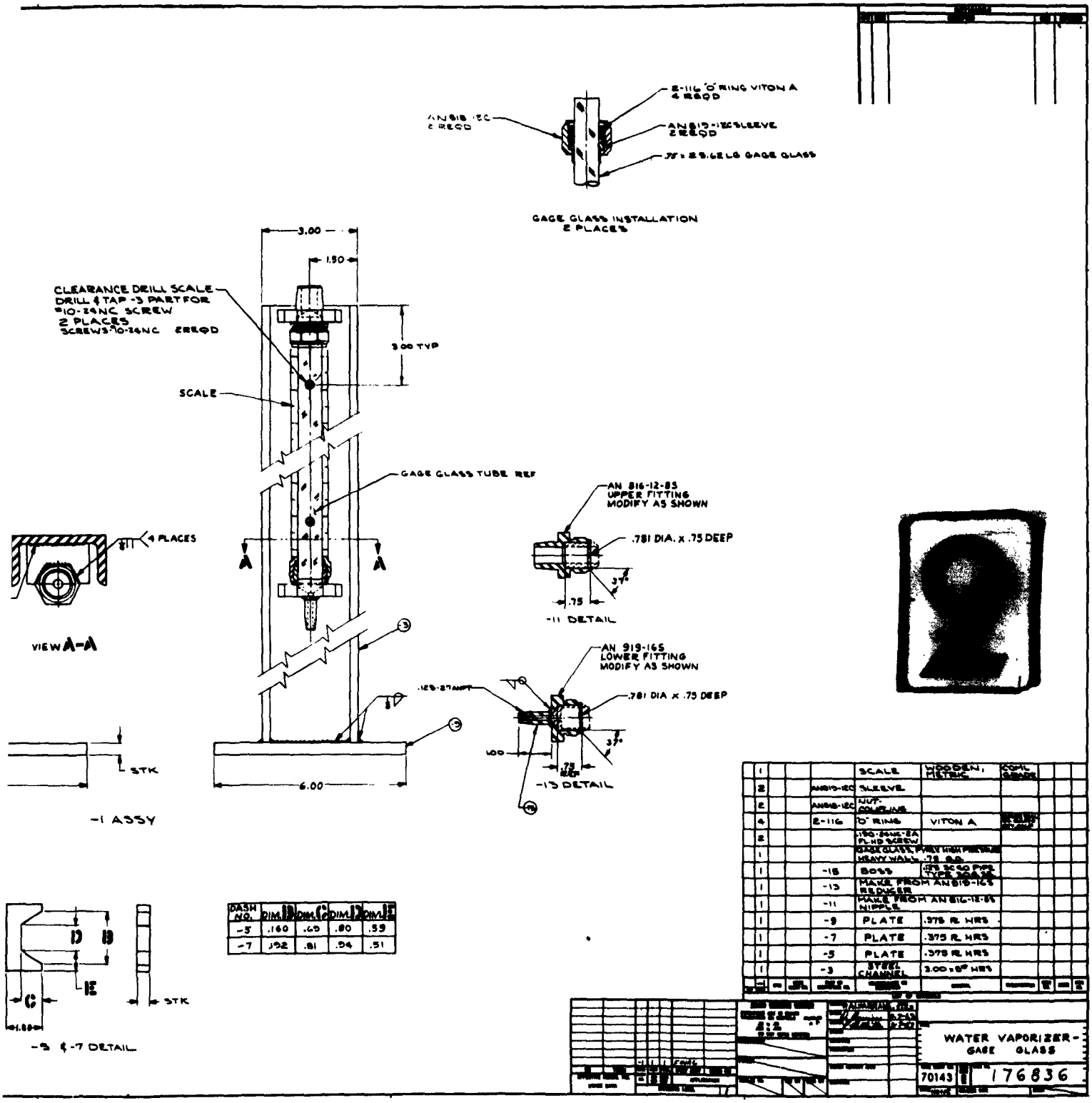

& MARK WITH PART NO.
AN816-12C
2 REQD
GAGE GLASS INSTALLATI
2 PLACES
3.00
1.50
CLEARANCE DRILL SCALE
DRILL & TAP -3 PART FOR
#10-24NC SCREW
2 PLACES
SCREWS #10-24NC
3.00 TYP
SCALE
GAGE GLASS TUBE REF
38.62
40.00
(REF)
25.00
4 PLACES
4 PLACES
VIEW A-A
AN 816-12-83
UPPER FITTI
MODIFY AS S
.781 DIA.
.75
-11 DETAIL
AN 919-16S
LOWER FITTI
MODIFY AS SH
.781 DIA
.100
.75
-13 DETAIL
STK
9.00
6.00
-1 ASSY
2.00
STK
-5 & -7 DETAIL
DASH NO.
DIM B
DIM C
DIM D
DIM E
-5
.160
.65
.80
.59
-7
.192
.81
.94
.51

Figure 10



DASH NO.	DIM B	DIM C	DIM D	DIM E
-5	.160	.69	.80	.59
-7	.192	.81	.94	.51

1				SCALE	WOODEN, METRIC	COML GRADE
2			AN815-12C	SLEEVE		
2			AN818-12C	NUT-COUPLING		
4			2-116	"O" RING	VITON A	
2				.150-32UNF-2A FLHD SCREW		
1				GAGE GLASS, PYREX HIGH PRESSURE HEAVY WALL, .75 O.D.		
1			-15	BOSS	.375 SCH 80 PIPE TYPE 304 SS	
1			-13	MAKE FROM AN815-16S REDUCER		
1			-11	MAKE FROM AN816-12-8S NIPPLE		
1			-9	PLATE	.375 R. HRS	
1			-7	PLATE	.375 R. HRS	
1			-5	PLATE	.375 R. HRS	
1			-3	STEEL CHANNEL	3.00 x 6# HRS	

Figure 10

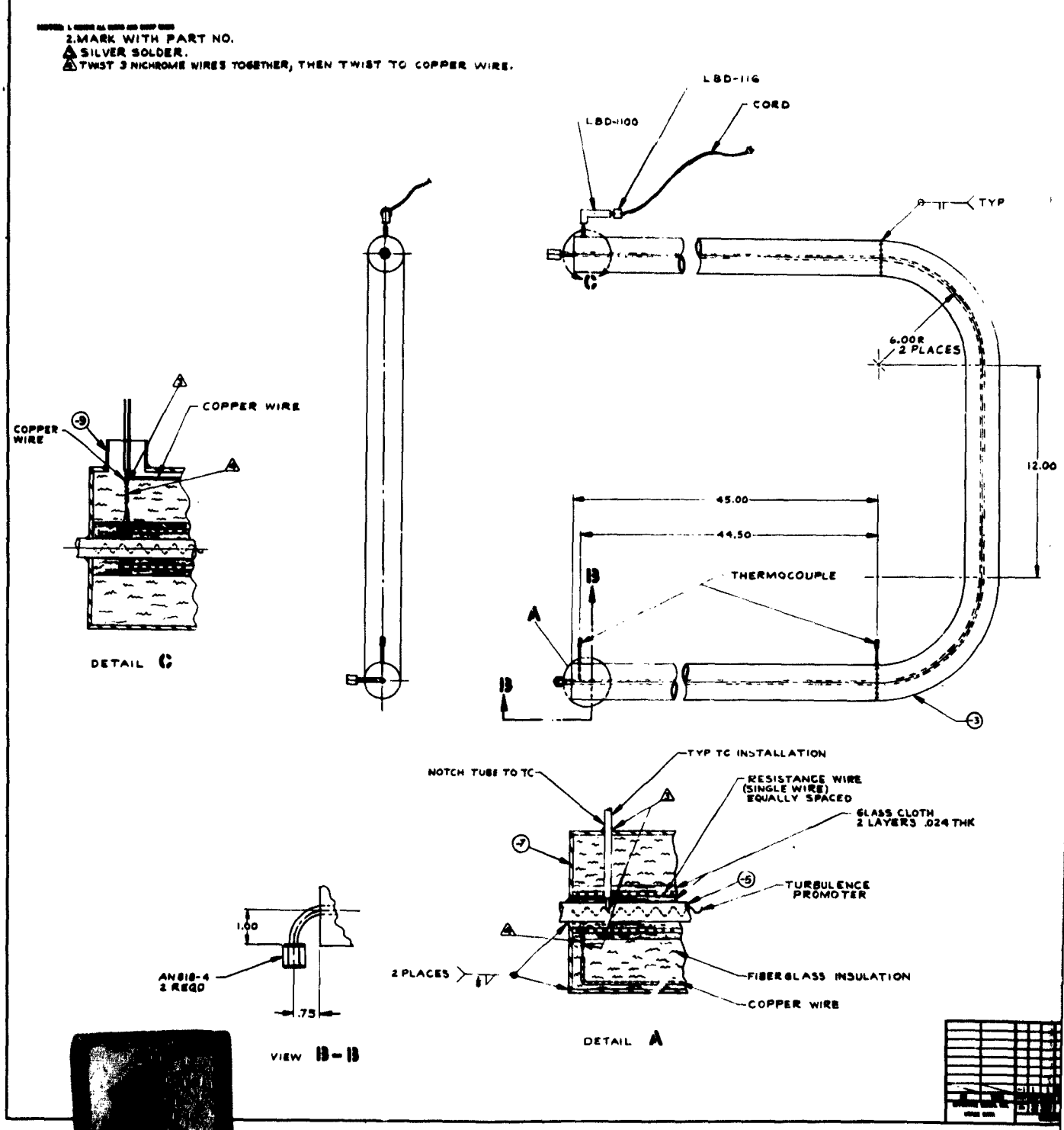

2.MARK WITH PART NO.
SILVER SOLDER.
TWIST 3 NICHROME WIRES TOGETHER, THEN TWIST TO COPPER WIRE.
LBD-116
LBD-1100
CORD
TYP
6.00R
2 PLACES
12.00
45.00
44.50
THERMOCOUPLE
COPPER WIRE
COPPER WIRE
DETAIL C
TYP TC INSTALLATION
NOTCH TUBE TO TC
RESISTANCE WIRE (SINGLE WIRE) EQUALLY SPACED
GLASS CLOTH 2 LAYERS .024 THK
TURBULENCE PROMOTER
FIBERGLASS INSULATION
COPPER WIRE
2 PLACES
DETAIL A
1.00
AN818-4 2 REQD
.75
VIEW B-B

Figure 11

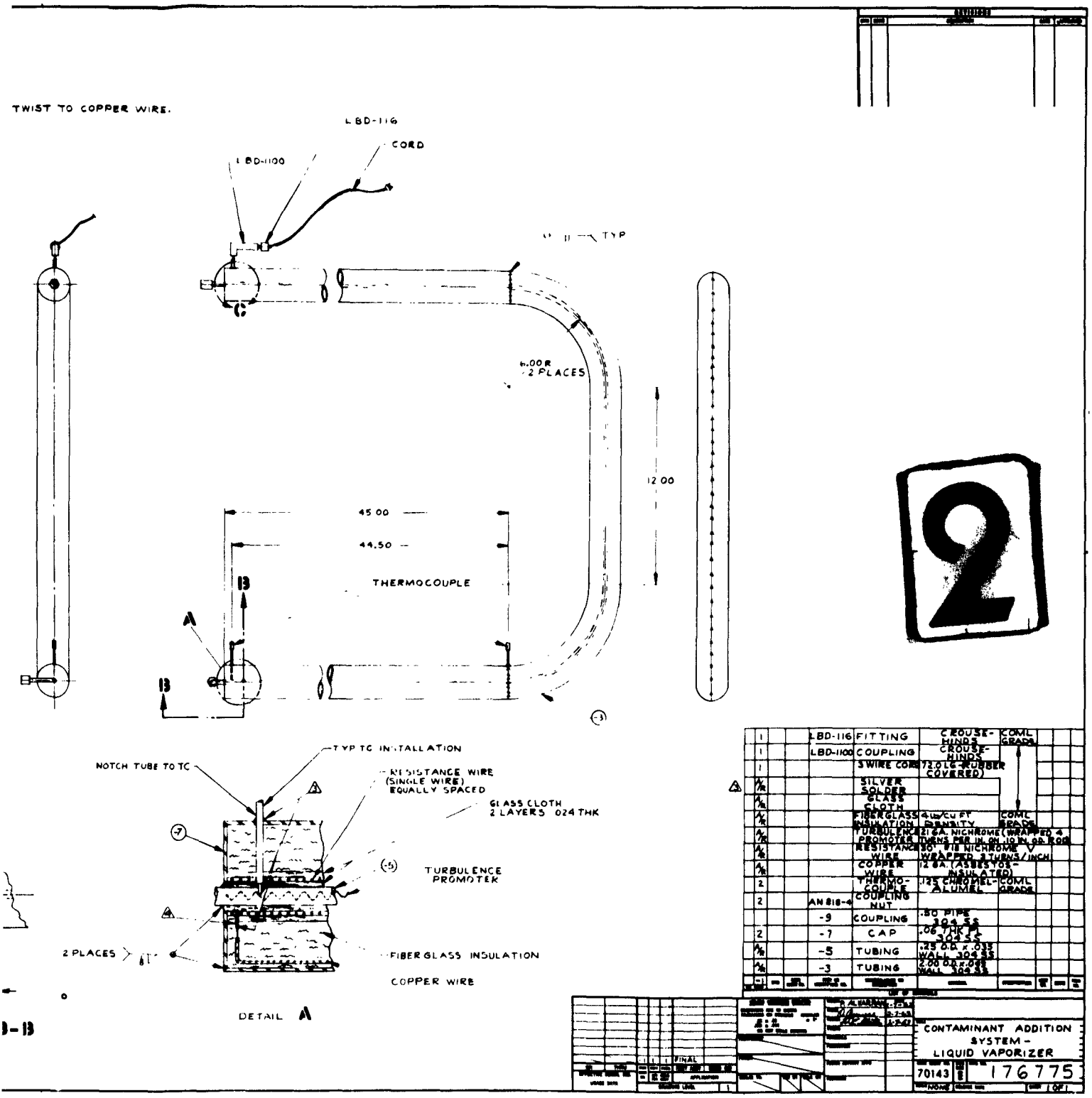

TWIST TO COPPER WIRE.
LBD-116
CORD
LBD-1100
TYP
6.00R
2 PLACES
12.00
45.00
44.50
THERMOCOUPLE
B
A
B
TYP TC INSTALLATION
NOTCH TUBE TO TC
RESISTANCE WIRE (SINGLE WIRE) EQUALLY SPACED
GLASS CLOTH 2 LAYERS .024 THK
TURBULENCE PROMOTER
2 PLACES
FIBERGLASS INSULATION
COPPER WIRE
DETAIL A
1 LBD-116 FITTING CROUSE-HINDS COML GRADE
1 LBD-1100 COUPLING CROUSE-HINDS
SWIRE CORD 72.0 LG -RUBBER COVERED)
SILVER SOLDER
GLASS CLOTH
FIBERGLASS INSULATION 4 lb/cu FT DENSITY COML GRADE
TURBULENCE PROMOTER 21 GA. NICHROME WRAPPED 4 TURNS PER IN ON .10 IN OD ROD
RESISTANCE WIRE 30 GA. NICHROME WRAPPED 3 TURNS/INCH
COPPER WIRE 24 GA (ASBESTOS-INSULATED)
THERMO-COUPLE .125 CHROMEL-ALUMEL COML GRADE
2 AN 818-4 COUPLING NUT
-9 COUPLING .50 PIPE 304 SS
2 -7 CAP .06 THK SS 304 SS
-5 TUBING .25 O.D. X .035 WALL 304 SS
-3 TUBING 2.00 O.D. X .095 WALL 304 SS
CONTAMINANT ADDITION SYSTEM - LIQUID VAPORIZER
70143
176775

Figure 11

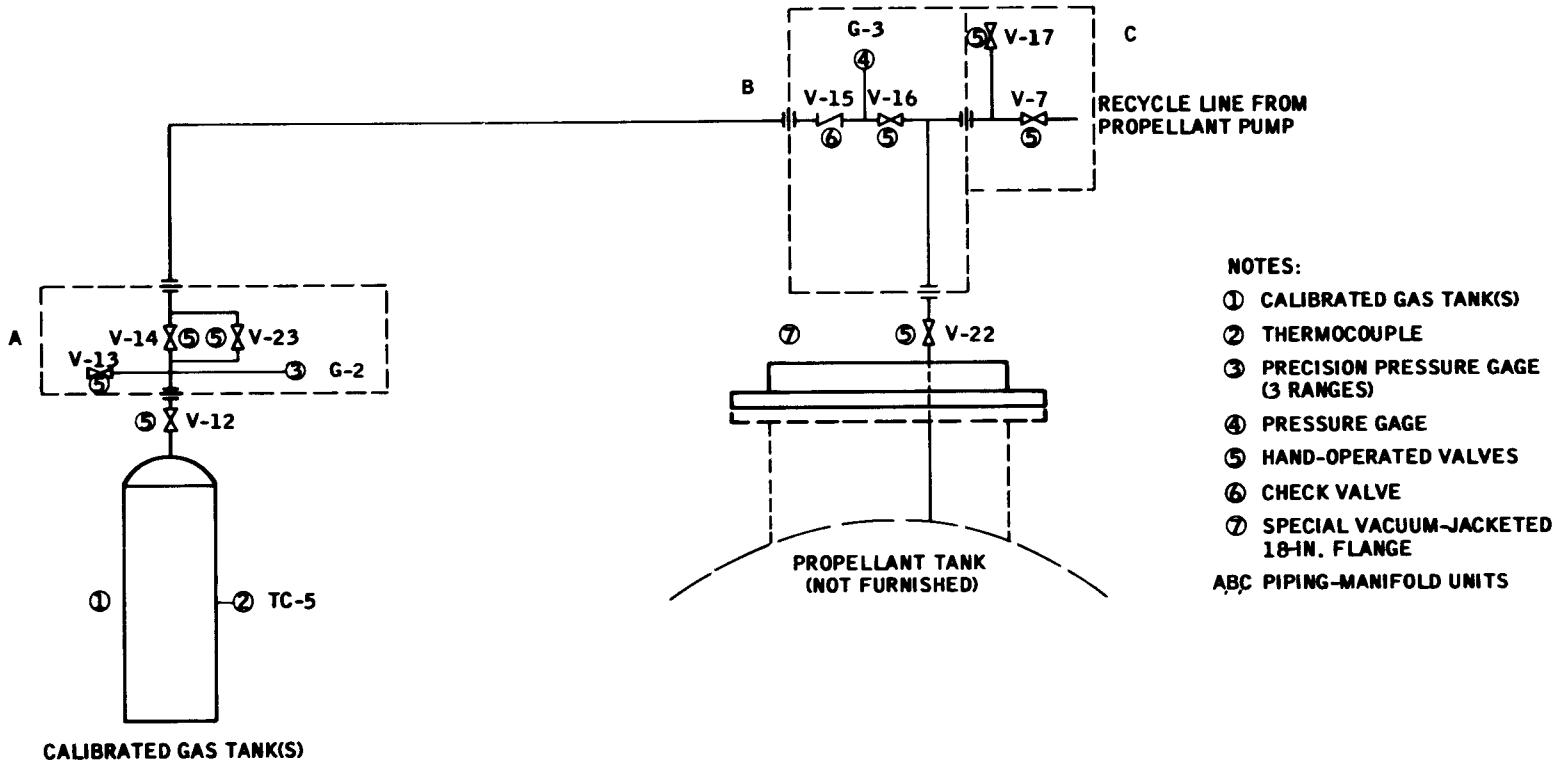


Figure 12

FLOW DIAGRAM FOR GASEOUS - CONTAMINANT ADDITION

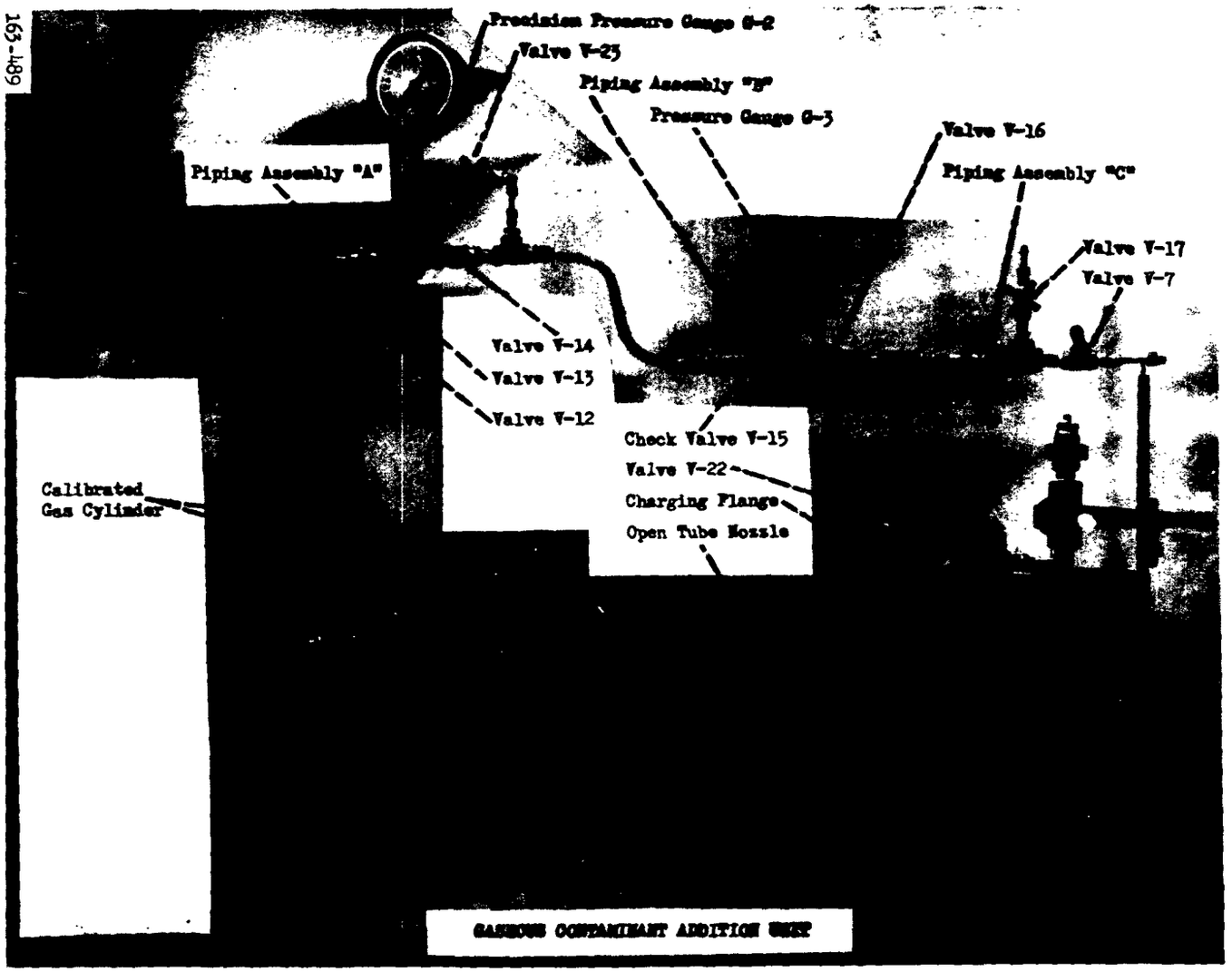

163-489
Precision Pressure Gauge G-2
Valve V-23
Piping Assembly "B"
Pressure Gauge G-3
Valve V-16
Piping Assembly "A"
Piping Assembly "C"
Valve V-17
Valve V-7
Valve V-14
Valve V-13
Valve V-12
Check Valve V-15
Valve V-22
Charging Flange
Open Tube Nozzle
Calibrated
Gas Cylinder
GASEOUS CONTAINMENT ADDITION UNIT

Figure 13

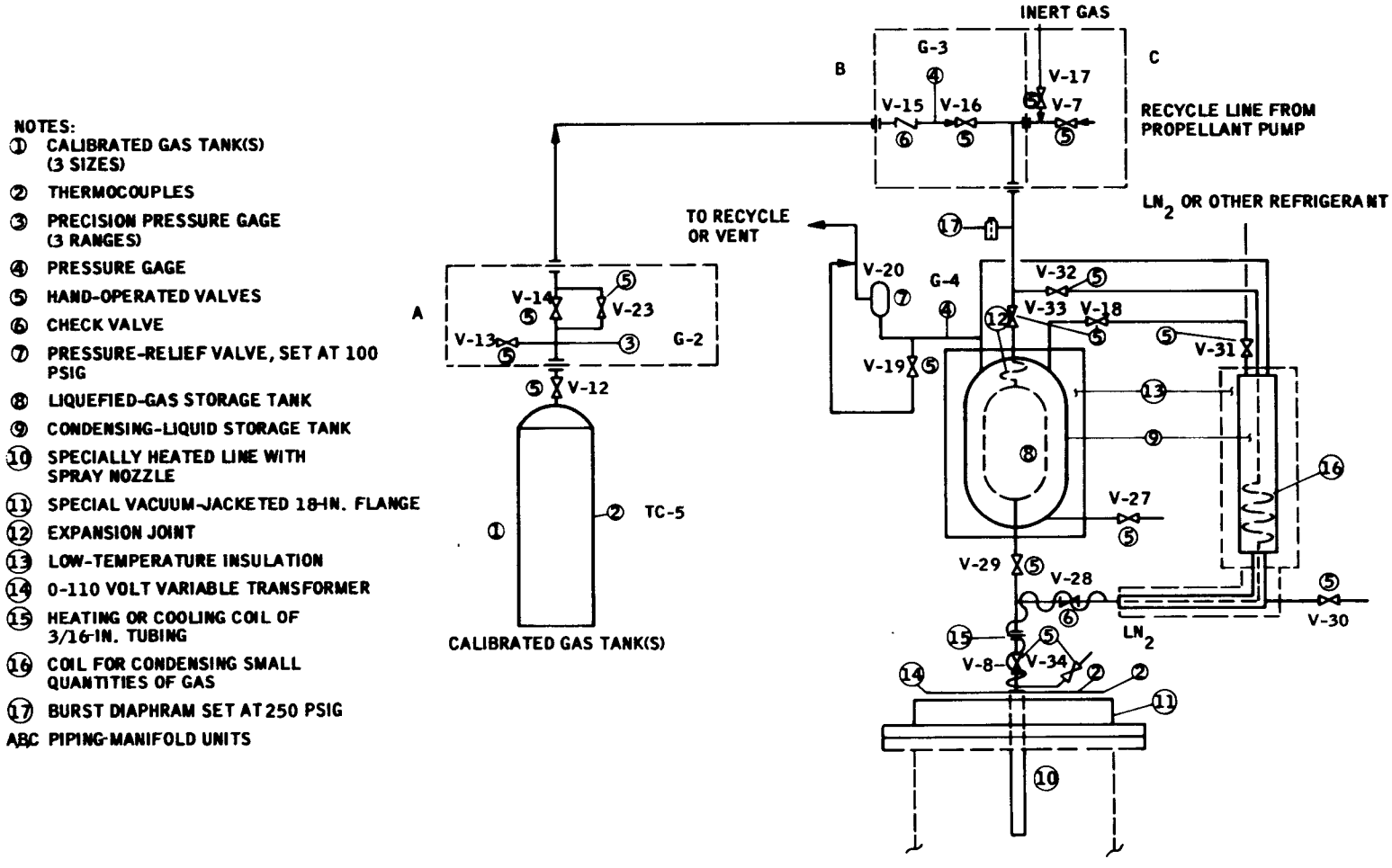


Figure 14

FLOW DIAGRAM FOR LIQUEFIED-GAS-CONTAMINANT ADDITION

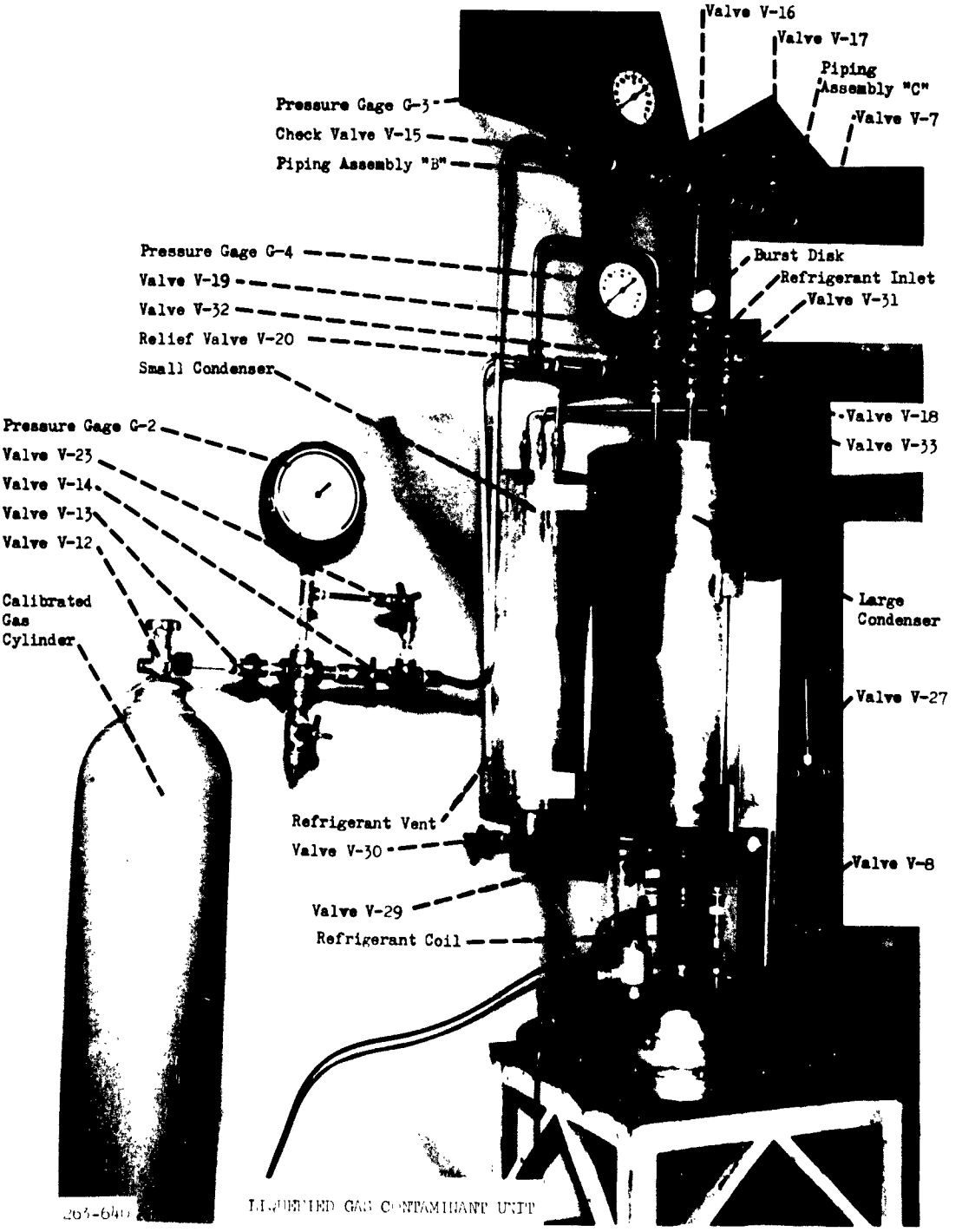
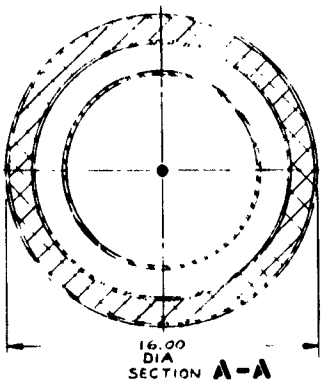

Valve V-16
Valve V-17
Piping Assembly "C"
Valve V-7
Pressure Gage G-3
Check Valve V-15
Piping Assembly "B"
Pressure Gage G-4
Valve V-19
Valve V-32
Relief Valve V-20
Small Condenser
Burst Disk
Refrigerant Inlet
Valve V-31
Valve V-18
Valve V-33
Pressure Gage G-2
Valve V-23
Valve V-14
Valve V-13
Valve V-12
Calibrated Gas Cylinder
Large Condenser
Valve V-27
Refrigerant Vent
Valve V-30
Valve V-8
Valve V-29
Refrigerant Coil
LIQUEFIED GAS CONTAMINANT UNIT

Figure 15

NOTES:

1. ⚠ ASSEMBLE INNER TANK WITH PIPES ATTACHED & WELD; PICKLE; PROOF TEST AT 400 PSIG, LEAK TEST AT 300 PSIG. (NO LEAKAGE ALLOWED)
2. ⚠ DRILL .6875 HOLE FOR CLEARANCE.
3. ⚠ CUT OUTER TANK IN TWO, ASSEMBLE INNER TANK, WELD TOGETHER, WELD ON COUPLINGS & INLET & OUTLET PIPES; PROOF TEST AT 300 PSIG, LEAK CHECK AT 150 PSIG.
4. ⚠ INSULATE & COVER WITH SS SHEET.
5. ⚠ DRILL CAPS FOR A PRESS FIT; DEBURR; PIPE MUST BE FLUSH WITH INNER SURFACE.
6. ⚠ CUT TO FIT.
7. MARK WITH PART NO.



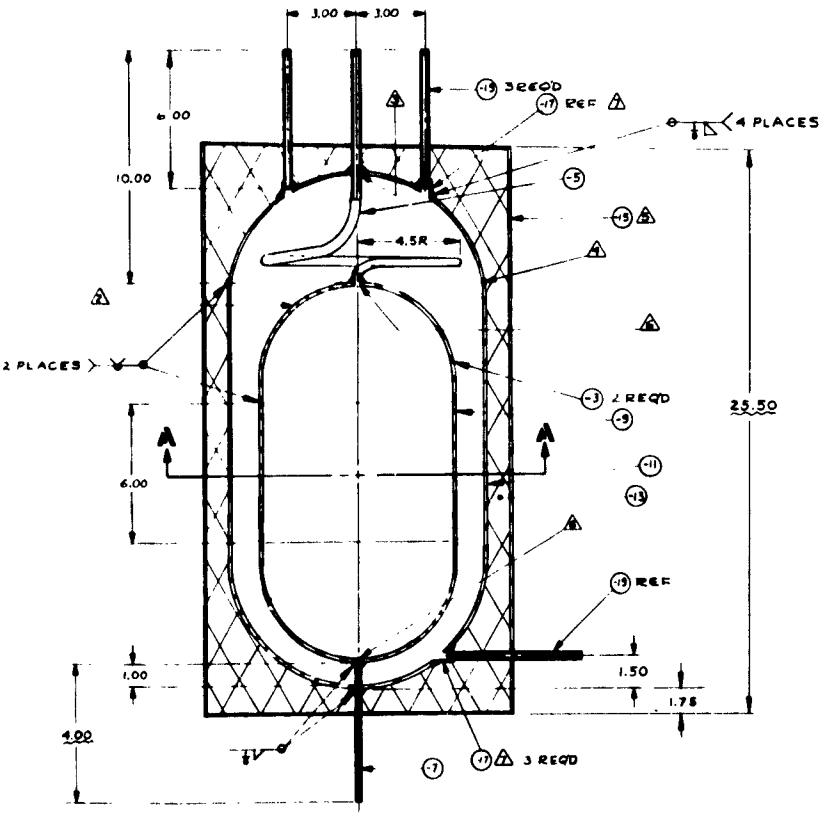
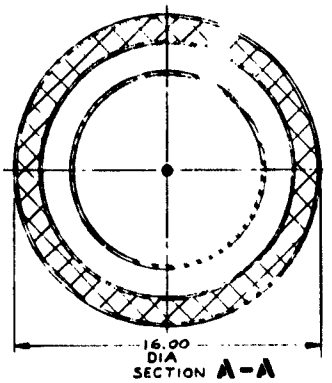


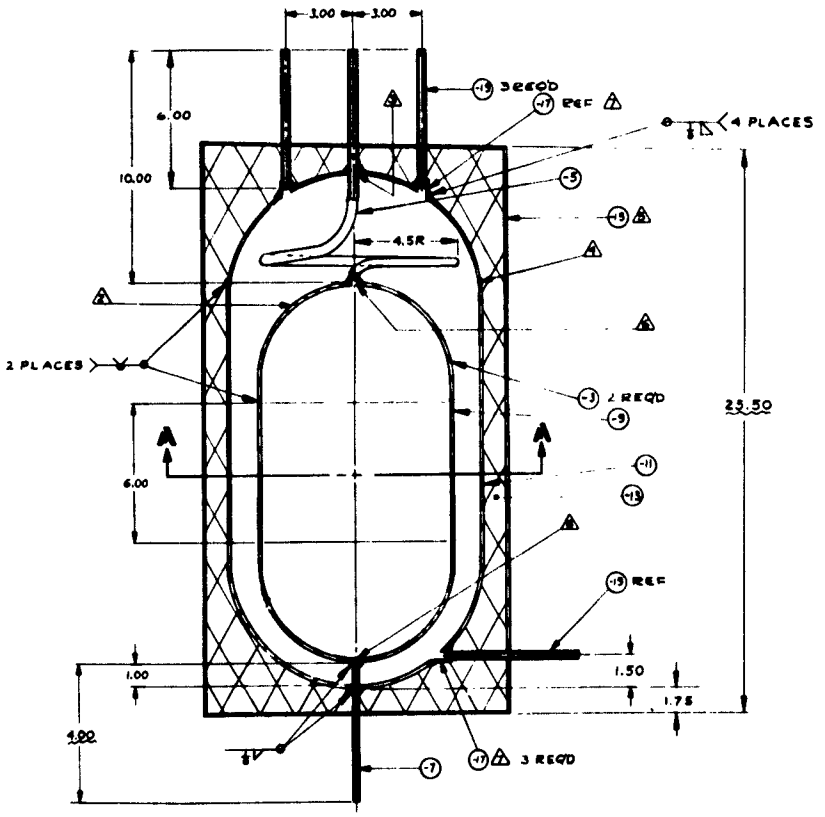
Figure 16

ED & WELD;
ST AT 300

ANK, WELD
UTLET PIPES;
T 150 PSIG.

: MUST BE





3		-19	NIPPLE	.375 PIPE SC 80, 304 SS	
3		-17	COUPLING	.375 PIPE SC 80, 304 SS	
1		-15	COVER	.062 THK TYPE 410 SS	
1/4		-13	INSULATION	2.00 POLYURETHANE FOAM	
1		-11	PRESSURE VESSEL	11 IN. I.D. x 23 IN. LG. 304 SS [illegible]	
1		-9	PIPE	SC 40, 304 SS	
1		-7	HVY PIPE	.25 PIPE, .719 WALL x 6.00 LG. SC 80, 304 SS	
1		-5	PIPE	.719 THK SO RTJ SC 40, 304 SS	
2		-3	WELDING CAP	6.00 IN. SC 40 TYPE 304 SS	COMC GRADE

GAS CONDENSATION & STORAGE TANK

70143 | 176834

Figure 16

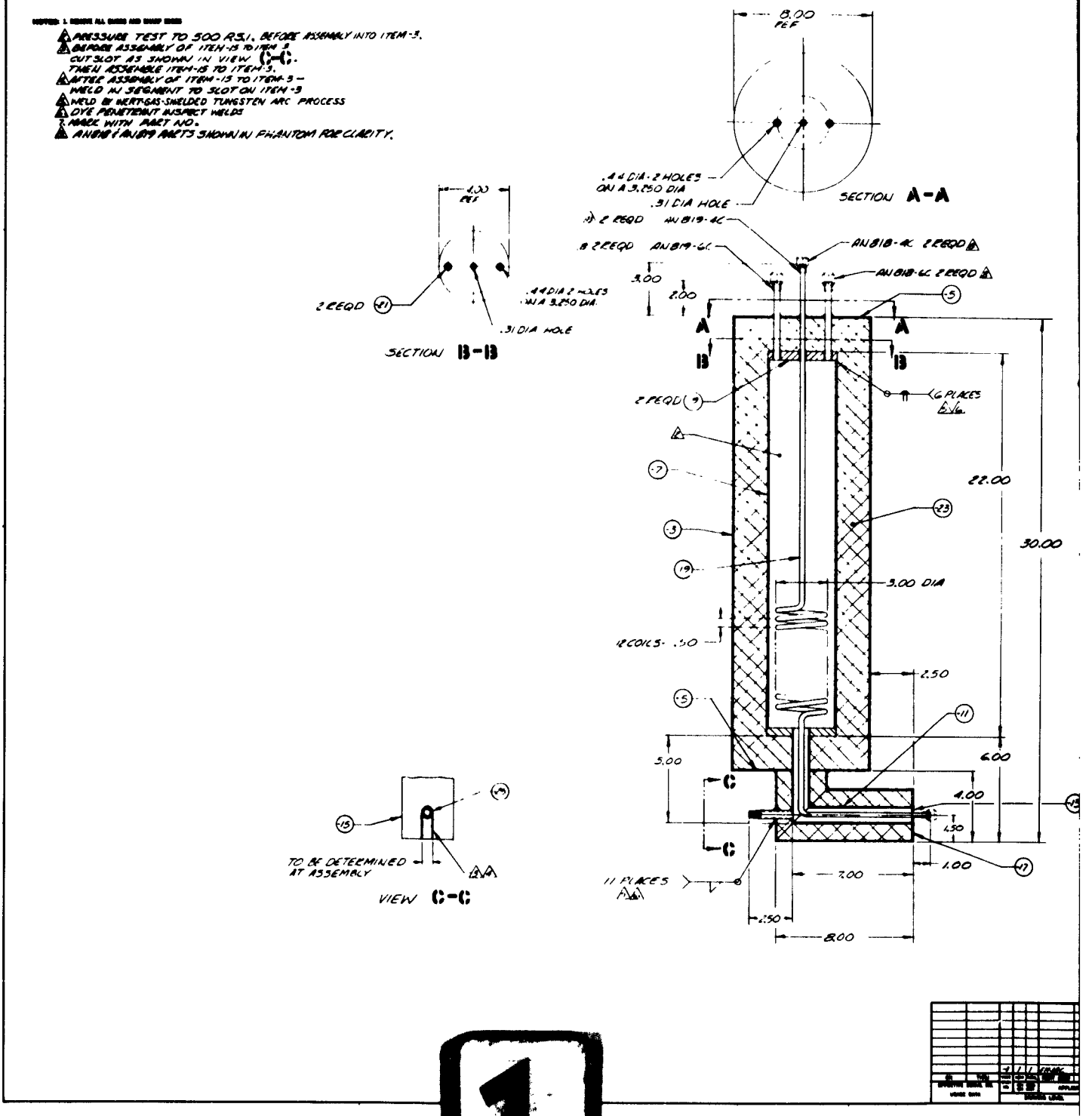
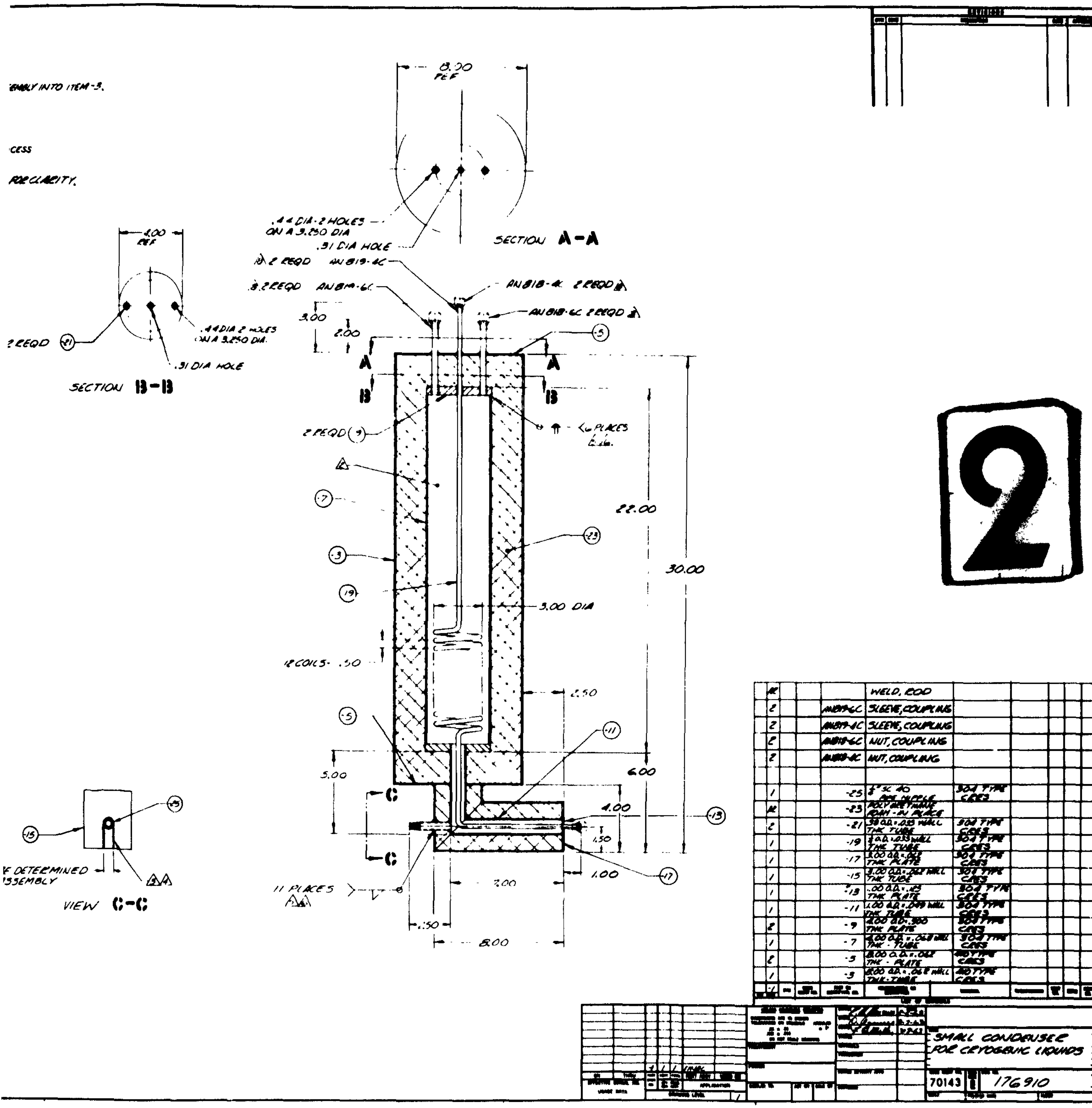

PRESSURE TEST TO 500 PSI. BEFORE ASSEMBLY INTO ITEM-3.
BEFORE ASSEMBLY OF ITEM-15 TO ITEM 3 CUT SLOT AS SHOWN IN VIEW C-C. THEN ASSEMBLE ITEM-15 TO ITEM-3.
AFTER ASSEMBLY OF ITEM-15 TO ITEM-3 — WELD IN SEGMENT TO SLOT ON ITEM-3
WELD BY INERT-GAS-SHIELDED TUNGSTEN ARC PROCESS
DYE PENETRANT INSPECT WELDS
MARK WITH PART NO.
AN818-4C AND AN819-4C PARTS SHOWN IN PHANTOM FOR CLARITY.
8.00 REF
.44 DIA-2 HOLES ON A 3.250 DIA
.31 DIA HOLE
SECTION A-A
2 REQD AN819-4C
AN818-4C 2 REQD
AN818-6C 2 REQD
3.00
2.00
1.00 REF
2 REQD
.44 DIA 2 HOLES ON A 3.250 DIA
.31 DIA HOLE
SECTION B-B
6 PLACES EVEN
22.00
30.00
3.00 DIA
12 COILS - .50
2.50
5.00
6.00
4.00
4.50
1.00
7.00
11 PLACES
2.50
8.00
TO BE DETERMINED AT ASSEMBLY
VIEW C-C

Figure 17



SECTION A-A
SECTION B-B
VIEW C-C
.44 DIA - 2 HOLES ON A 3.250 DIA
.31 DIA HOLE
AN 819-4C
AN 818-4C 2 REQD
AN 818-6C 2 REQD
2 REQD
22.00
30.00
3.00 DIA
12 COILS - .50
6.00
5.00
4.00
1.50
1.00
2.00
8.00
11 PLACES
WELD, ROD
SLEEVE, COUPLING
NUT, COUPLING
SMALL CONDENSER FOR CRYOGENIC LIQUIDS
70143
176910
2

Figure 17

NOTES:

① PRECISION SOLIDS-METERING INSTRUMENT
② SUPPORT FOR METER
③ HAND-OPERATED GLOBE VALVES
④ HAND-OPERATED BALL VALVES
⑤ SOLIDS-STORAGE CHAMBER
⑥ STAINLESS-STEEL UNION
⑦ SPECIAL VACUUM-JACKETED 18-IN. FLANGE
C PIPING MANIFOLD

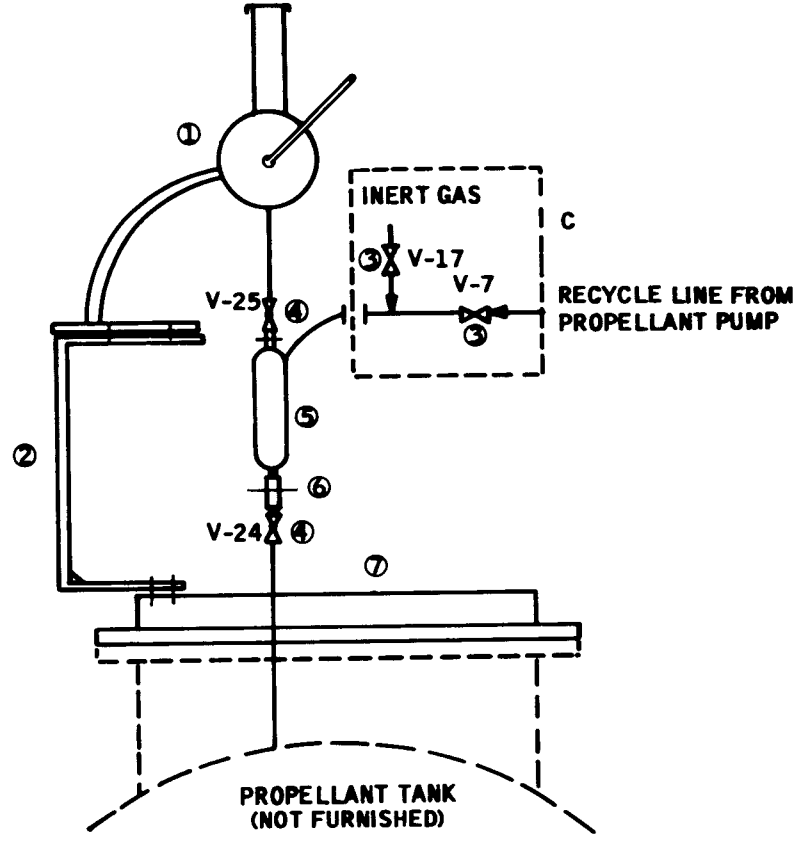


Figure 18

FLOW DIAGRAM FOR SOLID – CONTAMINANT ADDITION

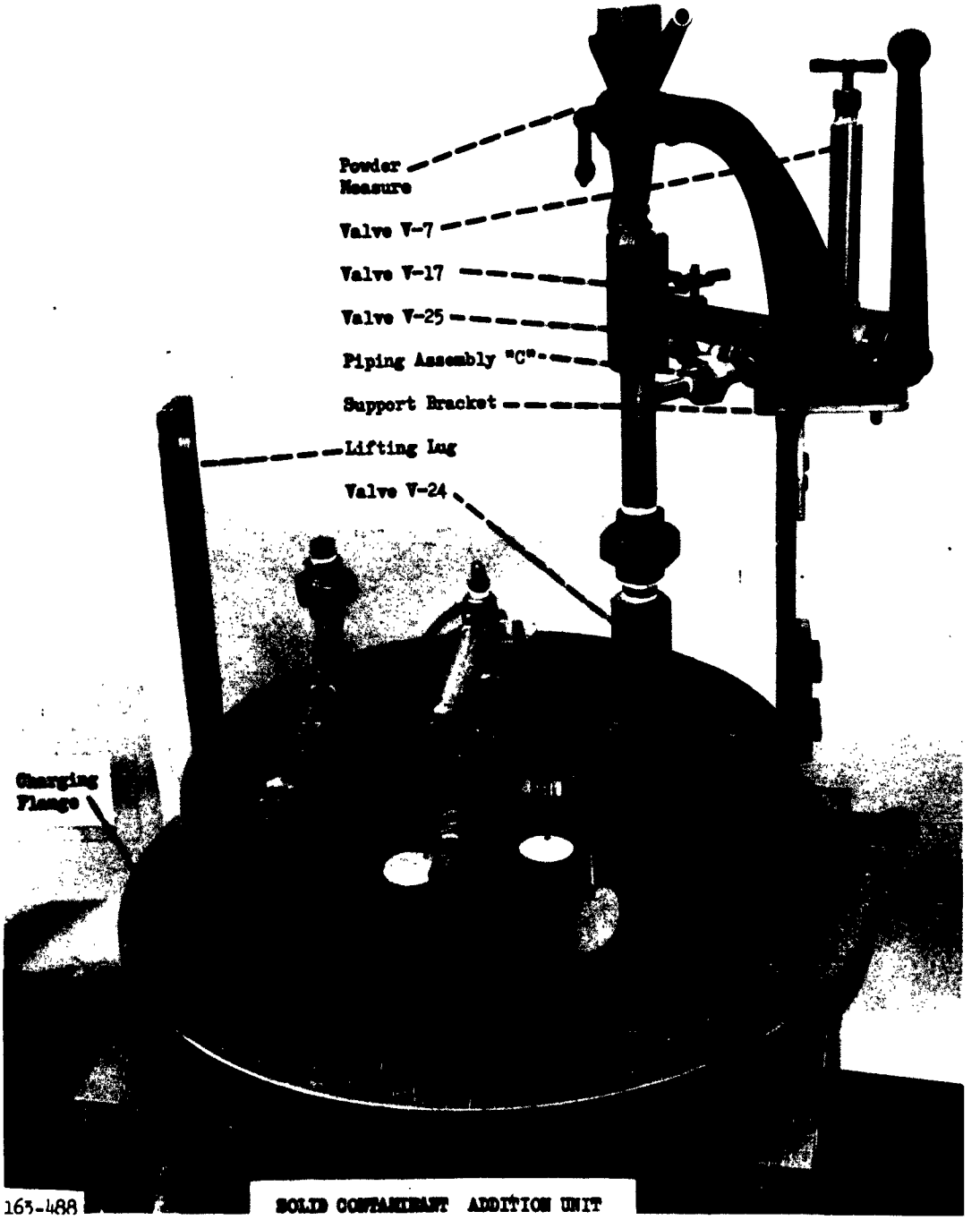
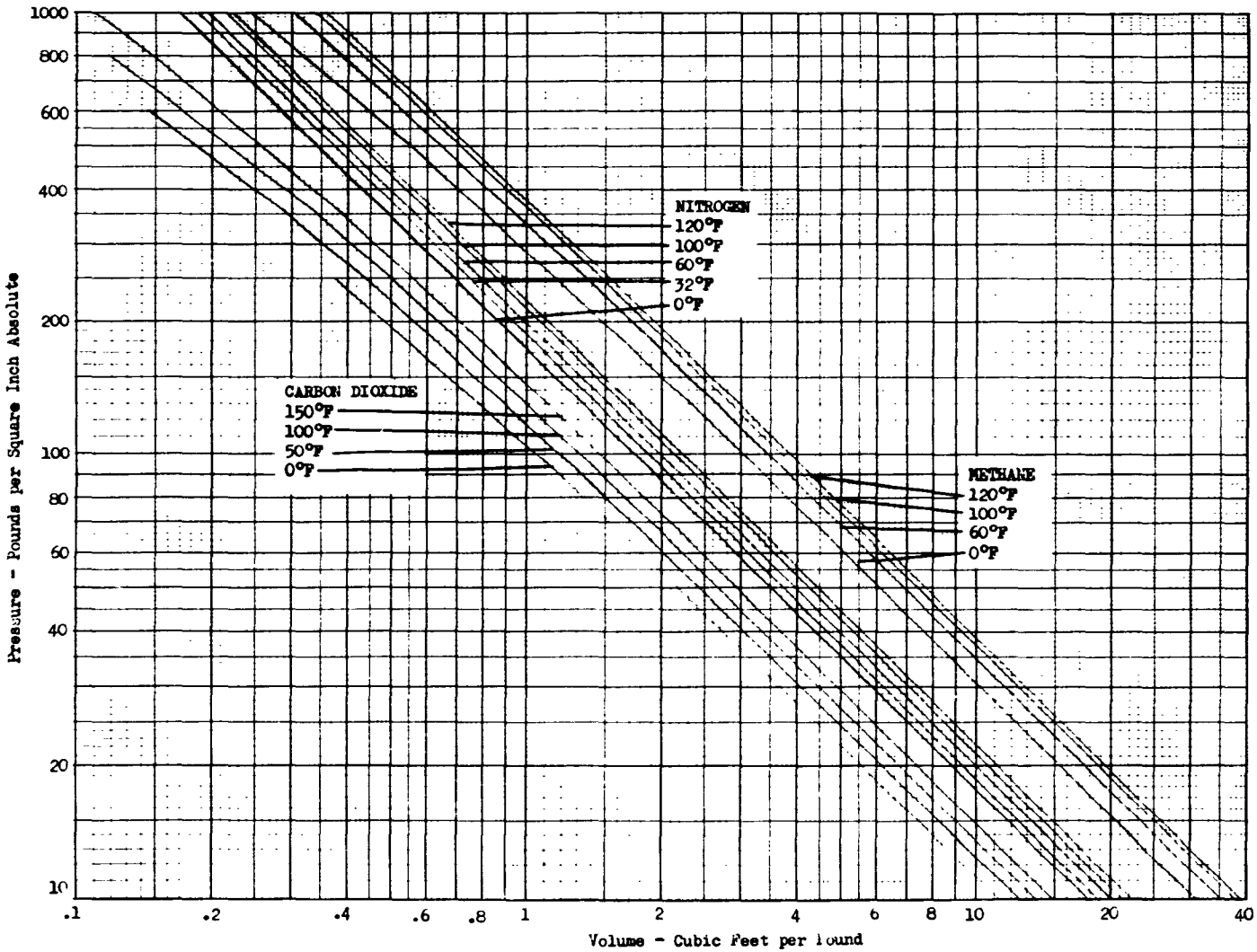

Powder Measure
Valve V-7
Valve V-17
Valve V-25
Piping Assembly "C"
Support Bracket
Lifting Lug
Valve V-24
Charging Flange
163-488
SOLID CONTAINMENT ADDITION UNIT

Figure 19



PROPERTIES OF SUPERHEATED GASES

Figure 20

TABLE 1

QUANTITIES OF CONTAMINANTS TO BE ADDED
TO 200 GALLONS OF PROPELLANT

Contaminant	Concentration		Required Accuracy	Required Quantity* grams	
	Minimum	Maximum	+%	Minimum	Maximum
Gaseous CH_4	15 ppm	3000 ppm	10	0.8	4080
Liquid CH_4	15 ppm	3000 ppm	10	0.8	4080
Gaseous N_2	160 ppm	5000 ppm	10	8.0	6810
Liquid N_2	160 ppm	5000 ppm	10	8.0	6810
Gaseous CO_2	10 ppm	5000 ppm	10	0.6	6810
Water vapor	10 ppm	50 ppm	10 to 20	0.6	68
Liquid water	10 ppm	1000 ppm	10 to 20	0.6	1360
Flake iron oxide	1 mg/gal	50 mg/gal	6	0.2	10
Silicon dioxide	1 mg/gal	50 mg/gal	6	0.2	10

*The minimum quantities given are for addition to LH_2, which has the lowest density of the propellants involved. The maximum quantities given are for addition to ClF_3, which has the highest density.

TABLE 2

EQUIPMENT SUMMARY, VALVES*

	V-1	V-2	V-3	V-4	V-5
Service	Feed-tank vent	Feed-tank fill	Feed-tank outlet	Pump calibration	Pump shutoff
Make	Hoke	Jamesbury	Hoke	Hoke	Hoke
Type	Needle	Ball, E.S.	Needle	Needle	Needle
Model No.	PY 271	D33TT	PY 273	PY 271	PY 271
Size, in.	1/4	1/2	1/2	1/4	1/4
Series, psi	5000	800	5000	5000	5000
Body material	316 SS	SS	316 SS	316 SS	316 SS
Valve trim	SS	SS	SS	SS	SS
Seat material	SS	Teflon	SS	SS	SS
Packing	Teflon	Teflon	Teflon	Teflon	Teflon
Typical fluid	GN_2	Water	Water	Water	Water
Flow-temp range	Amb	Amb	Amb	Amb	Amb
Pressure, psig	0-100	0-100	0-100	0-200	0-200
Fig. No.	6	6	6	6	6
Lubrication	No	No	No	No	No

*Throughout table, V-1, etc. are valve numbers, all connections are threaded, and Fig. No. refers to the figures presented in this report.

TABLE 2 (cont.)

	V-6	V-7	V-8	V-9	V-10
Service	Pump discharge	Propellant recycle	Spray-tube inlet	Gage-glass fill	Gage-glass pressurize
Make	Circle Seal	Dragon	Dragon	Jamesbury	Hoke
Type	Poppet check	Needle, E.S.	Needle, E.S.	Ball, E.S.	Needle
Model No.	220T-2PP	808	808	D33TT	PY 271
Size, in.	1/4	3/8	1/4	1/2	1/4
Series, psi	3000	10,000	10,000	800	5000
Body material	SS	316 SS	316 SS	SS	316 SS
Valve trim	SS	SS	SS	SS	SS
Seat material	Teflon (O-ring)	SS	SS	Teflon	SS
Packing	Teflon	Teflon	Teflon	Teflon	Teflon
Typical fluid	Water	LF_2	LF_2	Water	GN_2
Flow-temp range	Amb	-423°F to amb	-423°F to amb	Amb	Amb
Pressure, psi	0-200	0-50	0-200	0-100	0-100
Fig. No.	6	12,14,18	6,8,14	8	8
Lubrication	No	No	No	No	No
Cracking pressure	8 psi	-	-	-	-

TABLE 2 (cont.)

	V-11	V-12	V-13	V-14	V-15
Service	Gage-glass drain	Gas-cylinder shutoff	Gas-manifold fill or vent	Gas control	Gas line
Make	Hoke	Hoke	Hoke	Hoke	Circle Seal
Type	Needle	Needle	Needle	Needle	Poppet check
Model No.	PY 270	PY 273	PY 273	PY 273	200T-4PP
Size, in.	1/8	1/2	1/2	1/2	1/2
Series, psi	5000	5000	5000	5000	3000
Body material	316 SS	316 SS	316 SS	316 SS	SS
Valve trim	SS	SS	SS	SS	SS
Seat material	SS	SS	SS	SS	Teflon (O-ring)
Packing	Teflon	Teflon	Teflon	Teflon	Teflon
Typical fluid	Water	CH_4	CH_4	CH_4	CH_4
Flow-temp range	Amb	Amb	Amb	Amb	Amb
Pressure, psig	0-100	0-2000	0-2000	0-2000	0-200
Fig. No.	8	12,14	12,14	12,14	12,14
Lubrication	No	No	No	No	No
Cracking pressure	-	-	-	-	8 psi

TABLE 2 (cont.)

	V-16	V-17	V-18	V-19	V-20
Service	Gas-line shutoff	Inert-gas purge	Condenser-jacket inlet	Condenser-jacket outlet	Condenser-jacket outlet
Make	Dragon	Hoke	Dragon	Hoke	Circle Seal
Type	Needle, E.S.	Needle	Needle, E.S.	Needle	In-line relief
Model No.	808	PY 271	808	PY 273	K 5120T-4MP-100
Size, in.	1/2	1/4	3/8	1/2	1/2
Series, psi	10,000	5,000	10,000	5,000	2,400
Body material	316 SS	316 SS	316 SS	316 SS	SS
Valve trim	SS	SS	SS	SS	SS
Seat material	SS	SS	SS	SS	Teflon
Packing	Teflon	Teflon	Teflon	Teflon	Teflon
Typical fluid	CH_4	GN_2	LN_2	LN_2	LN_2
Flow-temp range	-423°F to amb	Amb	-320°F to amb	Same	Same
Pressure, psig	0-200	0-200	0-200	0-200	0-100
Fig. No.	12,14	12,14,18	14	14	14
Lubrication	No	No	No	No	No
Cracking pressure	-	-	-	-	100 psi

TABLE 2 (cont.)

	V-21	V-22	V-23	V-24	V-25
Service	Pump discharge	Gas-tube inlet	Gas control	Solids-tube inlet	Solids-chamber inlet
Make	Circle Seal	Dragon	Hoke	Jamesbury	Jamesbury
Type	In-line relief	Needle, E.S.	Needle	Ball	Ball
Model No.	5120T-2MP-200	808	PY 270	HEP(HV)33MT	HEP(HV)33MT
Size, in.	1/4	1/2	1/8	3/4	3/4
Series, psi	2400	10,000	5000	800	800
Body material	SS	316 SS	316 SS	SS	SS
Valve trim	SS	SS	SS	SS	SS
Seat material	Teflon	SS	SS	Teflon	Teflon
Packing	Teflon	Teflon	Teflon	Teflon	Teflon
Typical fluid	Water	CH_4	CH_4	Silica-LH_2	Silica-LH_2
Flow-temp range	32-150°F	Amb	Amb	-423 to +200°F	Same
Pressure, psi	0-200	0-200	0-2000	0-200	0-200
Fig. No.	6	12	12,14	18	18
Lubrication	No	No	No	No	No
Cracking pressure	200 psi	-	-	-	-

TABLE 2 (cont.)

	V-26	V-27	V-28	V-29	V-30
Service	Propellant recycle	Condenser-jacket drain	Small-condenser drain	Large-condenser shutoff	Small-condenser-jacket drain
Make	Hoke	Dragon	Circle Seal	Dragon	Hoke
Type	Needle	Needle, E.S.	Poppet check	Needle, E.S.	Needle
Model No.	PY 271	808	220T-1PP-11	808	PY 271
Size, in.	1/4	3/8	1/4	1/4	1/4
Series, psi	5000	10,000	3000	10,000	5000
Body material	316 SS	316 SS	SS	316 SS	316 SS
Valve trim	SS	SS	SS	SS	SS
Seat material	SS	SS	Teflon (O-ring)	SS	SS
Packing	Teflon	Teflon	Teflon	Teflon	Teflon
Typical fluid	LF_2	LN_2	LN_2	LCH_4	LN_2
Flow-temp range	←	—	$-320^{\circ}F$ to amb	—	→
Pressure, psi	0-200	0-200	0-200	0-200	0-200
Fig. No.	6	14	14	14	14
Lubrication	No	No	No	No	No
Cracking pressure	-	-	11 psi	-	-

TABLE 2 (cont.)

	V-31	V-32	V-33	V-34
Service	LN_2 inlet to condenser	Small-condenser gas inlet	Large-condenser gas inlet	LN_2-tracer-line vent
Make	Dragon	Hoke	Hoke	Hoke
Type	Needle, E.S.	Needle	Needle	Needle
Model No.	808	Y-346H	Y-346H	Y-346H
Size, in.	1/4	3/8	3/8	1/8
Series, psi	10,000	3,000	3,000	3,000
Body material	316 SS	316 SS	316 SS	316 SS
Valve trim	SS	SS	SS	SS
Seat material	SS	SS	SS	SS
Packing	Teflon	Teflon	Teflon	Teflon
Typical fluid	LN_2	CH_4	CH_4	LN_2
Flow-temp range	-320°F to amb	Amb	Amb	-320°F to amb
Pressure, psi	0-200	0-200	0-200	0-20
Fig. No.	14	14	14	14
Lubrication	No	No	No	No

TABLE 3

EQUIPMENT SUMMARY, PRESSURE GAGES

	G-1 (G-4)*	G-2	G-2	G-2	G-3
Service	Pressurizing gas (refrigerant)	Gas contaminant	Gas contaminant	Gas-contaminant	Gas-contaminant
Make	Ashcroft	Ashcroft	Ashcroft	Ashcroft	Ashcroft
Model No.	1279	1082A	1082A	1082H	1279
Size, in.	4-1/2	6	6	6	4-1/2
Range, psi	0-300	0-60	0-600	0-2000	0-300
Graduations, psi	5	0.2	2	10	5
Fig. No.**	6	12,14	12,14	12,14	12,14

*Gage numbers.

**Figures presented in this report.

TABLE 4

EQUIPMENT SUMMARY, MISCELLANEOUS COMPONENTS

	Pump	Solids Feeder
Service	Liquid addition	Solids addition
Make	Proportioneers	Santa Anita Engineering Co.
Type	Duplex plunger	Volumetric
Model No.	Mod. 1106, Spec. 4	Microsetting Powder Measure
Size, in.	1/4 x 5/8	--
Drive	Electric motor XP/115/1/60-1/4 HP	Manual
Rate		
Minimum	0.04 gph	0.2 gram/rev
Maximum	4.2 gph (water)	9.2 grams/rev (silica)
Fig. No.*	6	18

*Figures presented in this report.

TABLE 5

REQUIRED UTILITIES AND ACCESSORIES

	Remarks
Power	115 v, 60 cps, single-phase
Steam	At 100 psi
Inert-gas supply	He or N_2
Propellant-recycle stream	--
Refrigerant	LN_2, or other
Water	For washdown
Water	Deionized or distilled
Variable transformer	500 watt
Variable transformer	1000 watt
Temperature-measuring device	Portable potentiometer or 4-point temperature recorder
Thermometer	For ambient-temperature measurement

TABLE 6

TESTS OF LIQUID-ADDITION UNIT

	1*	2	3	4	5	6	7	8	9	10	11
Cylinder size in use, in.	1/4	1/4	1/4	5/8	5/8	1/4	1/4	1/4	5/8	5/8	5/8
Stroke setting, %	10	10	100	50	100	20	50	100	20	50	100
No. of strokes	14	25	25	25	140	4	4	15	10	10	10
Water charged, calibration, ml	1.4	2.3	31	106	1100	1.2	2.6	20.3	19.0	41.0	80.7
Water delivered, ml	1.3	1.9	31	105	1100	1.1	2.4	19.7	18.5	39.8	80.1
Deviation, %	-7	-17	0	-1.0	0	-9	-8	-3	-3	-3	-0.8

Table 6

*Test No.

TABLE 7

TESTS OF WATER-VAPOR-ADDITION UNIT

Run No.	Elapsed Time min	Gage-Glass Level mm	Variac Setting volts		Temperature, °F				Water Added ml	Water Recovered ml	Deviation %	Remarks
					Vaporizer		Spray Tube					
			Vaporizer	Spray Tube	Mid	Out	Mid	Out				
1	0	530	45	60	523	359	215	304	-	-	-	Start addition
1	1	520	45	60	-	-	-	-	-	-	-	End addition
1	5	520	45	60	-	-	-	-	1.4	1.2	-14	Measure water
2	0	520	45-70	60	511	360	215	304	-	-	-	Start addition
2	2	510	70-45	60	-	-	-	-	-	-	-	End addition
2	4	510	45	60	-	-	-	-	1.4	1.4	0	Measure water
3	0	510	45-70	60	525	400	214	292	-	-	-	Start addition
3	5	460	70-45	60	623	-	-	-	-	-	-	End addition
3	9	460	45	60	622	480	215	298	7.0	7.0	0	Measure water
4	0	460	45-70	60	605	480	215	294	-	-	-	Start addition
4	3	410	70-45	60	631	-	-	-	-	-	-	End addition
4	8	410	45	60	-	-	-	-	7.0	6.9	-1.4	Measure water
5	0	410	45-70	60	610	529	-	-	-	-	-	Start addition
5	7	260	70-45	60	688	534	221	288	-	-	-	End addition
5	12	260	45	60	645	-	-	-	20.4	20.0	-2.0	Measure water

Table 7 (cont.)

Run No.	Elapsed Time min	Gage-Glass Level mm	Variac Setting volts		Temperature, °F				Water Added ml	Water Recovered ml	Deviation %	Remarks
					Vaporizer		Spray Tube					
			Vaporizer	Spray Tube	Mid	Out	Mid	Out				
6	0	590	44-70	60	503	284	297	336	-	-	-	Start addition
6	2	565	70-44	60	559	379	290	328	-	-	-	End addition
6	6	565	44	60	-	-	-	-	3.4	3.0	-12	Measure water
7	0	565	44-70	60	559	349	292	329	-	-	-	Start addition
7	10	44	70-50	60	663	644	290	318	-	-	-	End addition
7	14	44	50	60	301	645	294	324	70.9	69.8	-1.6	Measure water

TABLE 8

TESTS OF GAS-ADDITION UNIT

	1*	2	3	4
Gas-cylinder size (small, medium, large)	S	M	M	L
Pressure gage used (G-2),** psi	60	600	600	2000
Initial gas-cylinder pressure, psig	58.7	204	52	1190
Final gas-cylinder pressure, psig	8.1	52	4	113
Initial gas-cylinder temp, °F	59	60	59	68
Final gas-cylinder (WTM) temp, °F	59	57	59	32
Wet test meter (WTM) temp, °F	59	61	61	-
Uncorrected WTM volume, liters	1.635	42.03	14.42	***
Corrected WTM volume, standard liters	1.595	40.95	14.05	-
Calculated volume of gas added, standard liters	1.550	42.24	13.4	3166
Volume ratio (calculated/measured)	0.97	1.03	0.95	-
Calculated weight of gas added, g	1.83	50.0	15.8	3740
Time used in gas addition, min	4	4	7	5

* Test No.

** See Table 3.

*** This run was made to demonstrate that the larger quantities could be added in the required length of time. The flow rate was too high to be measured by the WTM.

TABLE 9

TESTS OF CRYOGENIC-LIQUID-ADDITION UNIT

Test No.	Elapsed Time min:sec	G-2 Gas-Cylinder Press., psig	G-4, Refrigerant-Reservoir Press. psig	G-3, Liquefied-Gas-Tank Press. psig	T-5 Gas-Cylinder Temp, °F	Remarks
				Large Unit*		
1	0:00	1790	2	5	68	V-23 opened
	4:00	1300	170	80	42	Condensing N_2
	14:00	735	175	105	35	Condensing N_2
	35:00	195	110	65	33	V-23 closed
	42:00	-	60	60	-	V-8 opened
	44:00	-	55	60	-	Discharging LN_2
	49:00	-	47	63	-	Discharging LN_2
	51:00	-	46	65	-	All LN_2 discharged
1	52:00	-	35	65	-	V-8 closed
2	0:00	422	8	13	64	V-23 opened
	1:00	340	85	27	46	Condensing N_2
	3:00	280	115	42	43	Condensing N_2
	3:25	224	130	38	43	V-23 closed
	22:45	-	90	95	-	V-8 opened
	23:45	-	90	95	-	Discharging LN_2
2	24:10	-	70	95	-	V-8 closed

*The calibrated volume of the large gas cylinder was 44.0 liters.

TABLE 9 (cont.)

Test No.	Elapsed Time min:sec	G-2 Gas-Cylinder Press., psig	G-4, Refrigerant-Reservoir Press.* psig	G-3, Liquefied-Gas-Tank Press. psig Small Unit**	T-5 Gas-Cylinder Temp, °F	Remarks
1	0:00	1435	0	0	73	V-23 opened
	2:00	1310		10	63	V-23 regulated for pressure drop of 1 psi at G-3
	3:00	1270		60	-	V-31 closed
	4:00	1220		75	63	--
	5:00	1190		85	-	Pressure on G-3 varying, being controlled with V-8
	6:00	1150		75	-	
	13:00	830		45	-	
	14:00	775		55	-	V-31 opened
	15:00	740		55	58	--
1	16:40	680	0	55	-	V-23 closed
2	0:00	1435	0	0	79	V-23 opened & regulated for pressure drop of about 1 psi/sec at G-3
	1:00	1390		25	-	--
	2:00	1230		85	-	--
	4:00	1145		100	-	--
	5:00	1060		115	58	V-31 left partially open
	6:00	980		100	-	--
	8:00	855		90	-	--
2	9:00	790	0	85	58	--

*See Sheet 3 for footnotes.

TABLE 9 (cont.)

Test No.	Elapsed Time min:sec	G-2 Gas-Cylinder Press., psig	G-4, Refrigerant-Reservoir Press.* psig	G-3, Liquefied-Gas-Tank Press. psig	T-5 Gas-Cylinder Temp, °F	Remarks
			Small Unit (cont.)**			
2	10:00	740	0	85	58	--
2	11:00	690	0	80	-	--
2	11:25	670	0	75	58	V-23 closed
3	0:00	680	0	0	60	V-23 opened
3	1:00	655	0	35	-	--
3	2:15	608	0	50	58	V-23 closed
4	0:00	670	0	0	62	V-23 opened
4	1:00	620	0	85	-	--
4	1:15	610	0	95	57	V-23 closed
5	0:00	608	0	0	58	V-23 opened
5	0:10	598	0	20	58	V-23 closed
6	0:00	612	0	0	60	V-23 opened
6	0:15	595	0	50	60	V-23 closed
7	0:00	595	0	0	60	V-23 opened
7	0:30	590	0	15	60	V-23 closed

*Vented at atmospheric pressure on all runs.

**The medium-size gas cylinder, with a volume of 4.080 liters, was used for Small Unit Runs 1 through 7. The quantities charged were as follows: Test 1, 231 g; Test 2, 231 g; Test 3, 24 g; Test 4, 17 g; Test 5, 4 g; Test 6, 5.7 g; Test 7, 1.7 g.

TABLE 10

TESTS OF SOLIDS-ADDITION UNIT

	1*	2	3	4
Powder-measure cylinder (large or small)	Small	Small	Large	Large
Cylinder setting	Smallest	Smallest	18 turns	18 turns
Number of charges used	1	2	1	1
Silica charged (calibrated weight, g)	0.215	0.430	5.65	5.65
Silica recovered, g	0.202	0.410	5.68	5.52
Deviation, %	-6.0	-4.6	+0.5	-1.2

*Test No.

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